

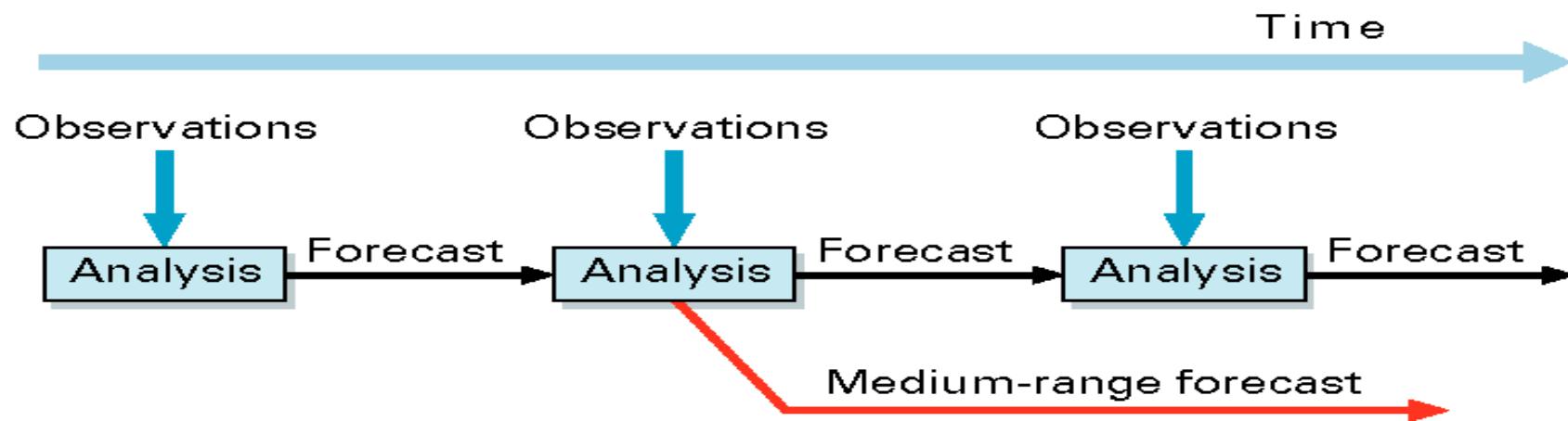
Assimilation of AIRS/IASI data at ECMWF

Peter Bauer, European Centre for Medium-Range Weather Forecasts

Tony McNally, Andrew Collard, Marco Matricardi, Wei Han, Carla Cardinali, Niels Bormann

- Initial performance / impact assessment
- Upgrades: Addition of water vapour channels, cloud-affected radiances, ozone
- Comprehensive observing system experiments
- Future upgrades
- Summary

Data assimilation system (4D-Var)



- The observations are used to correct errors in the short forecast from the previous analysis time.
- Every 12 hours we assimilate 4 – 8,000,000 observations to correct the 100,000,000 variables that define the model's virtual atmosphere.
- This is done by a careful 4-dimensional interpolation in space and time of the available observations; this operation takes as much computer power as the 10-day forecast.

~3,000,000 from
AIRS& IASI!

Data sources: Satellites

Radiances (→ brightness temperature = level 1):

- AMSU-A on NOAA-15/18/19, AQUA, Metop
- AMSU-B/MHS on NOAA-17/18/19, Metop
- SSM/I on F-15, AMSR-E on Aqua
- HIRS on NOAA-17/19, Metop
- AIRS on AQUA, IASI on Metop
- MVIRI on Meteosat-7, SEVIRI on Meteosat-9, GOES-11/12, MTSAT-1R imagers

Bending angles (→ bending angle = level 1):

- COSMIC (6 satellites), GRAS on Metop

Ozone (→ total column ozone = level 2):

- Total column ozone from SBUV on NOAA-17/18, OMI on Aura

Atmospheric Motion Vectors (→ wind speed = level 2):

- Meteosat-7/9, GOES-11/12, MTSAT-1R, MODIS on Terra/Aqua

Sea surface parameters (→ wind speed and wave height = level 2):

- Near-surface wind speed from Seawinds on QuikSCAT, ERS-2 scatterometer, ASCAT on Metop
- Significant wave height from RA-2/ASAR on Envisat, Jason altimeter

Initial performance assessment

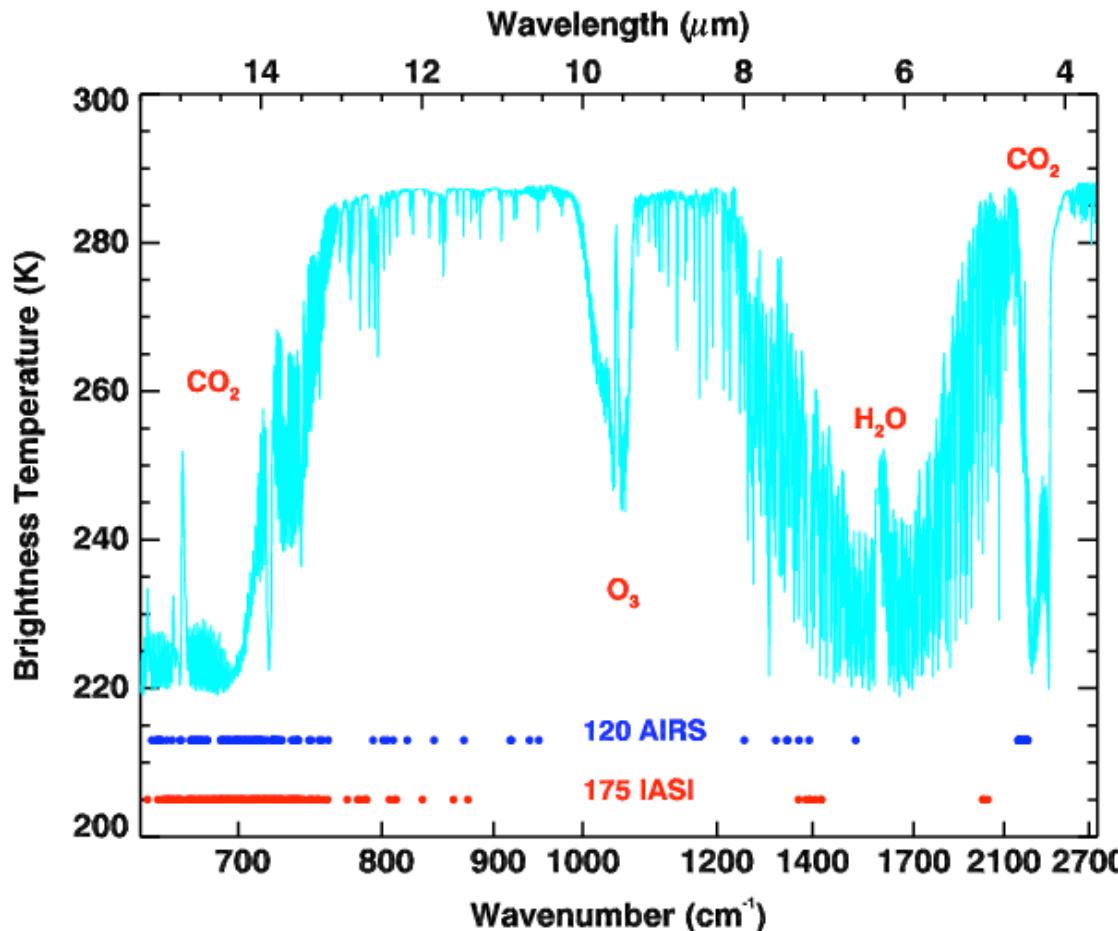
Upgrades: Addition of water vapour channels, cloud-affected radiances

Comprehensive observing system experiments

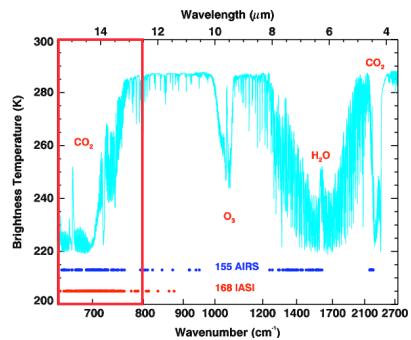
Future upgrades

Summary

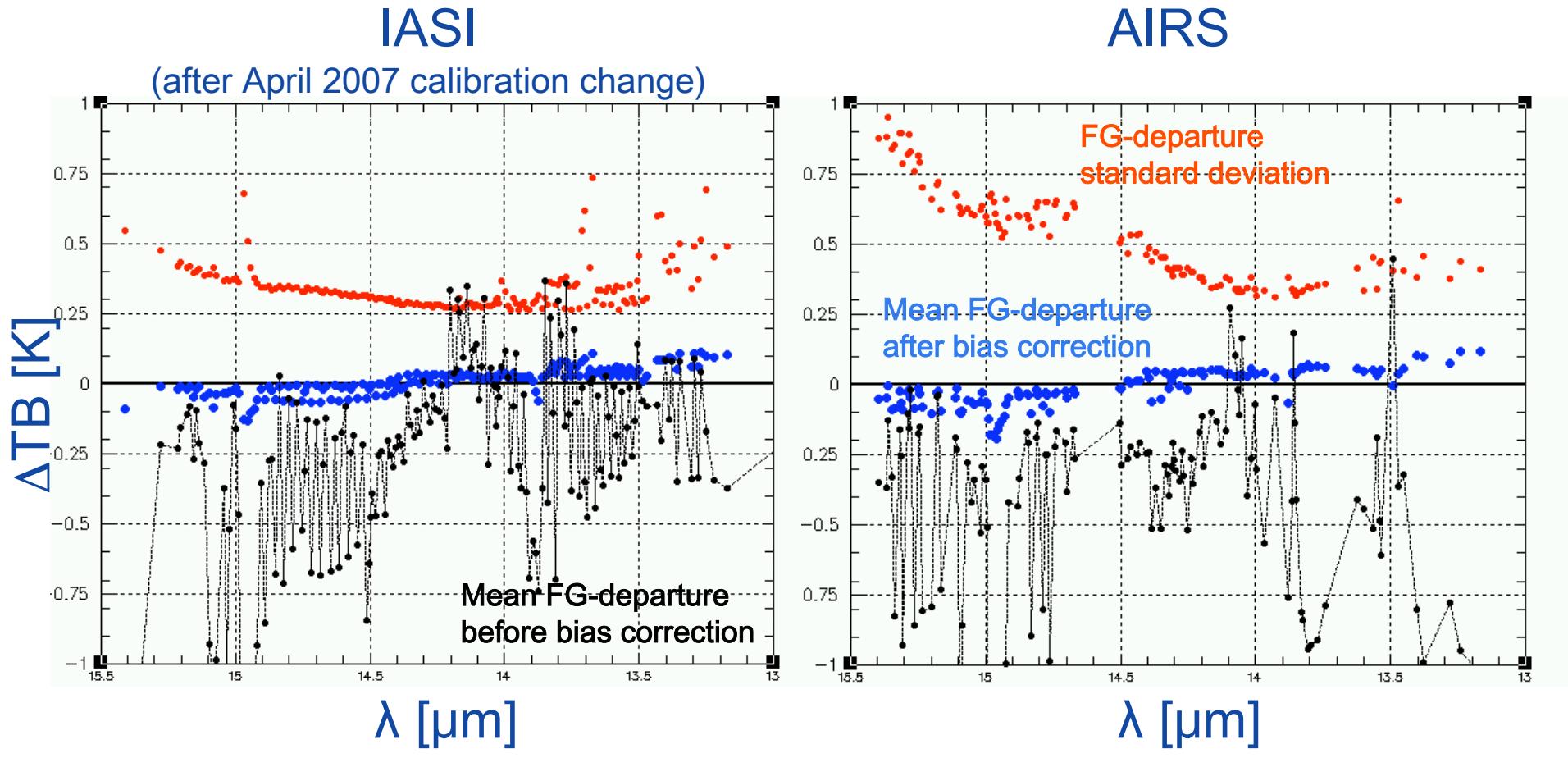
Current use of AIRS/IASI data



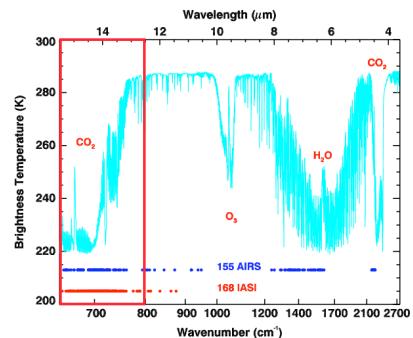
- AIRS CO₂ and H₂O channels assimilated since October 2003 (324 channels, 1/9 FOV).
- IASI CO₂/H₂O channels assimilated since June 2007/March 2009 (8461 channels, 1/4 FOV).
- Assimilated in clear-sky areas and above clouds; since September 2009 in fully overcast situations, AIRS (not IASI) over land surfaces/sea-ice.
- Continuous revision of channel usage, quality control: Ozone channels, PC RT.



Noise: AIRS vs. IASI data



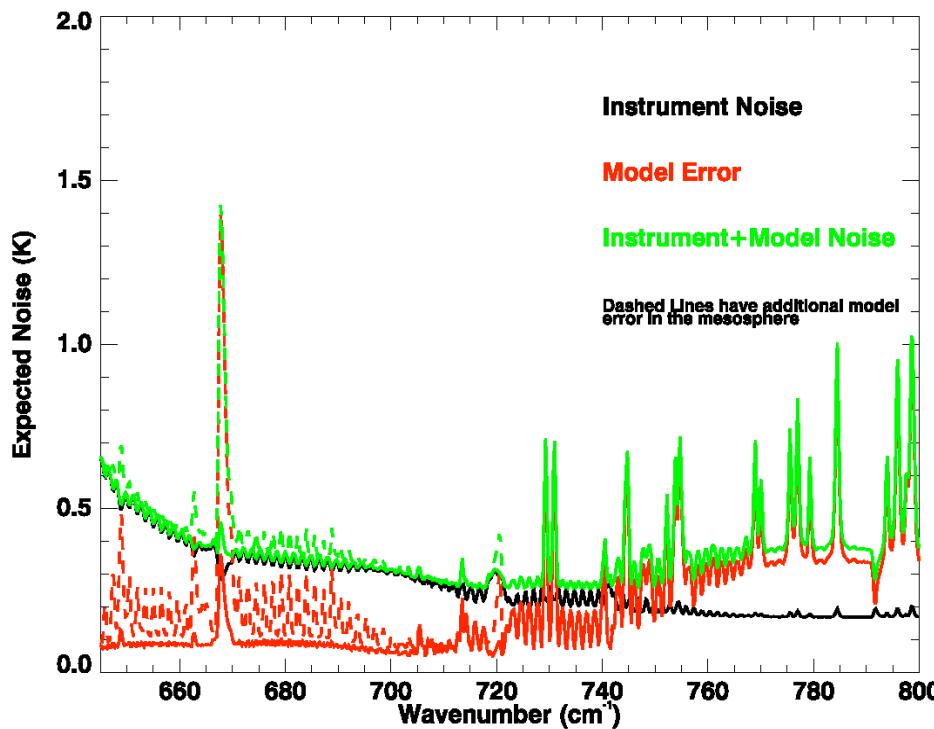
(A. Collard)



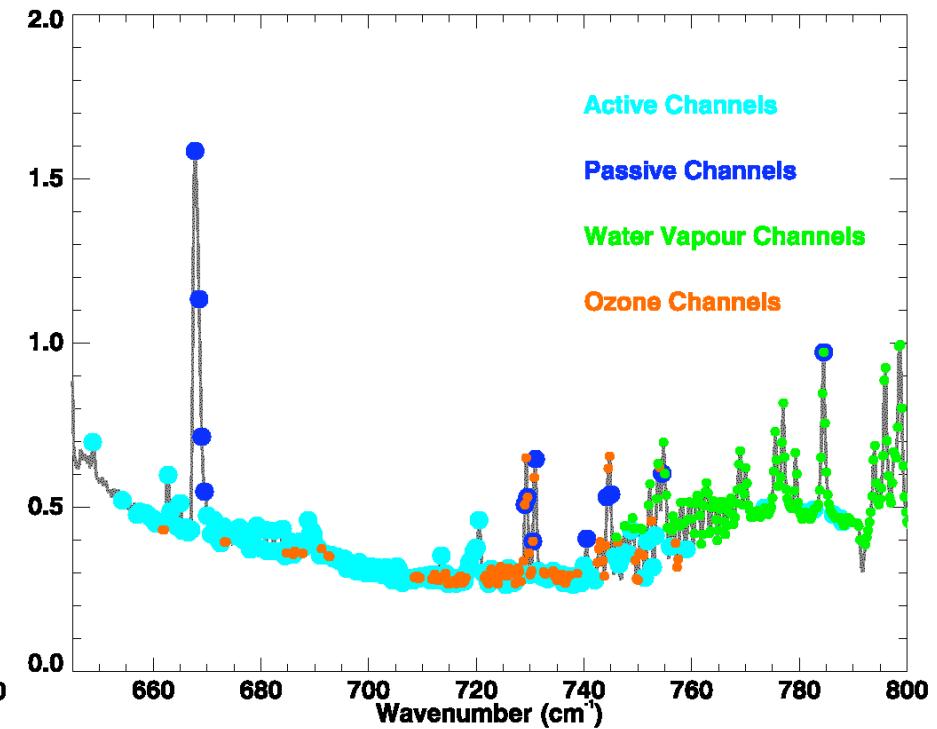
IASI: Model minus observations

First-guess departure standard deviations
in 15 μm CO_2 -band

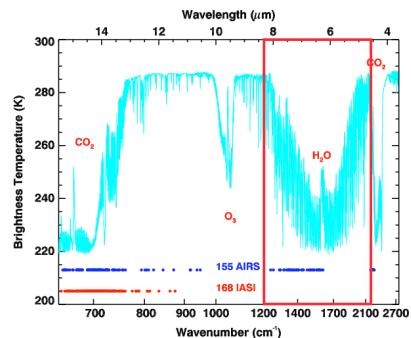
Calculated



Observed



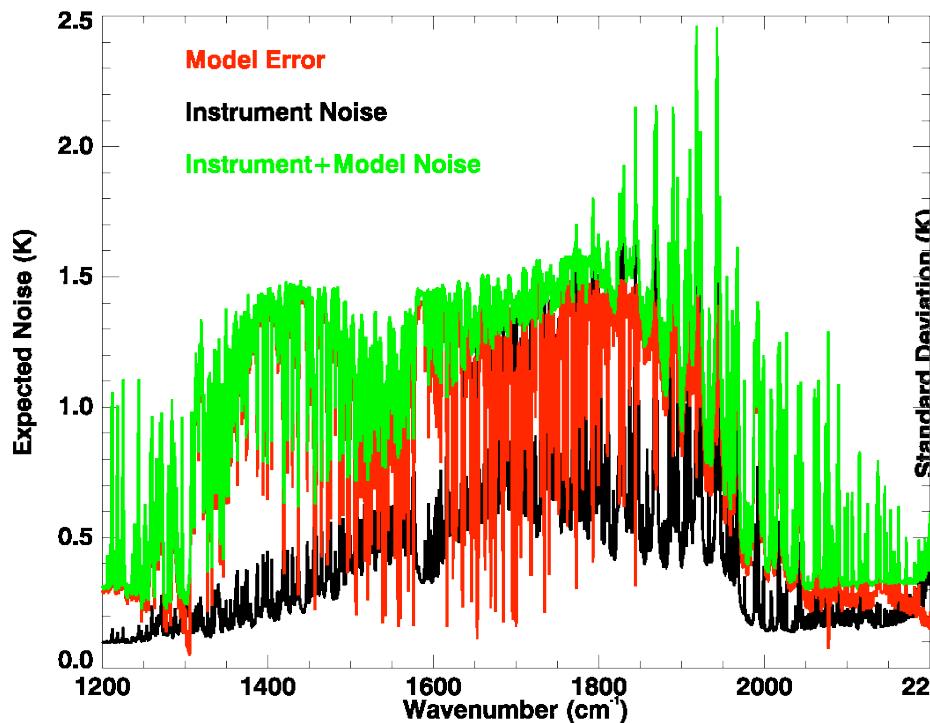
(A. Collard)



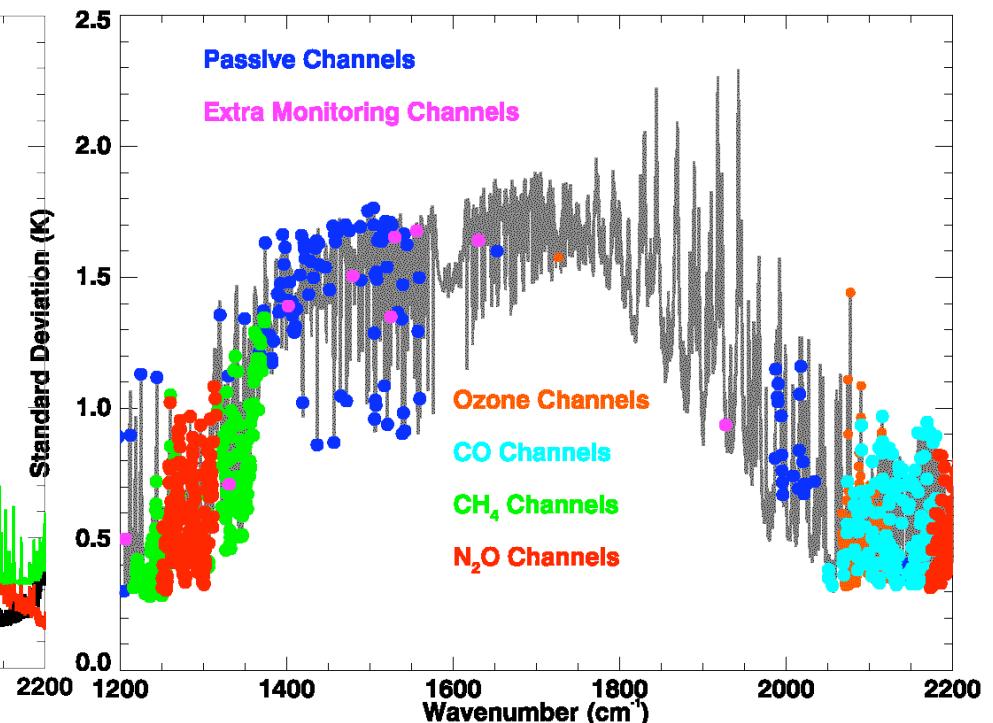
IASI: Model minus observations

First-guess departure standard deviations
in H_2O -band

Calculated



Observed



(A. Collard)

Initial performance assessment

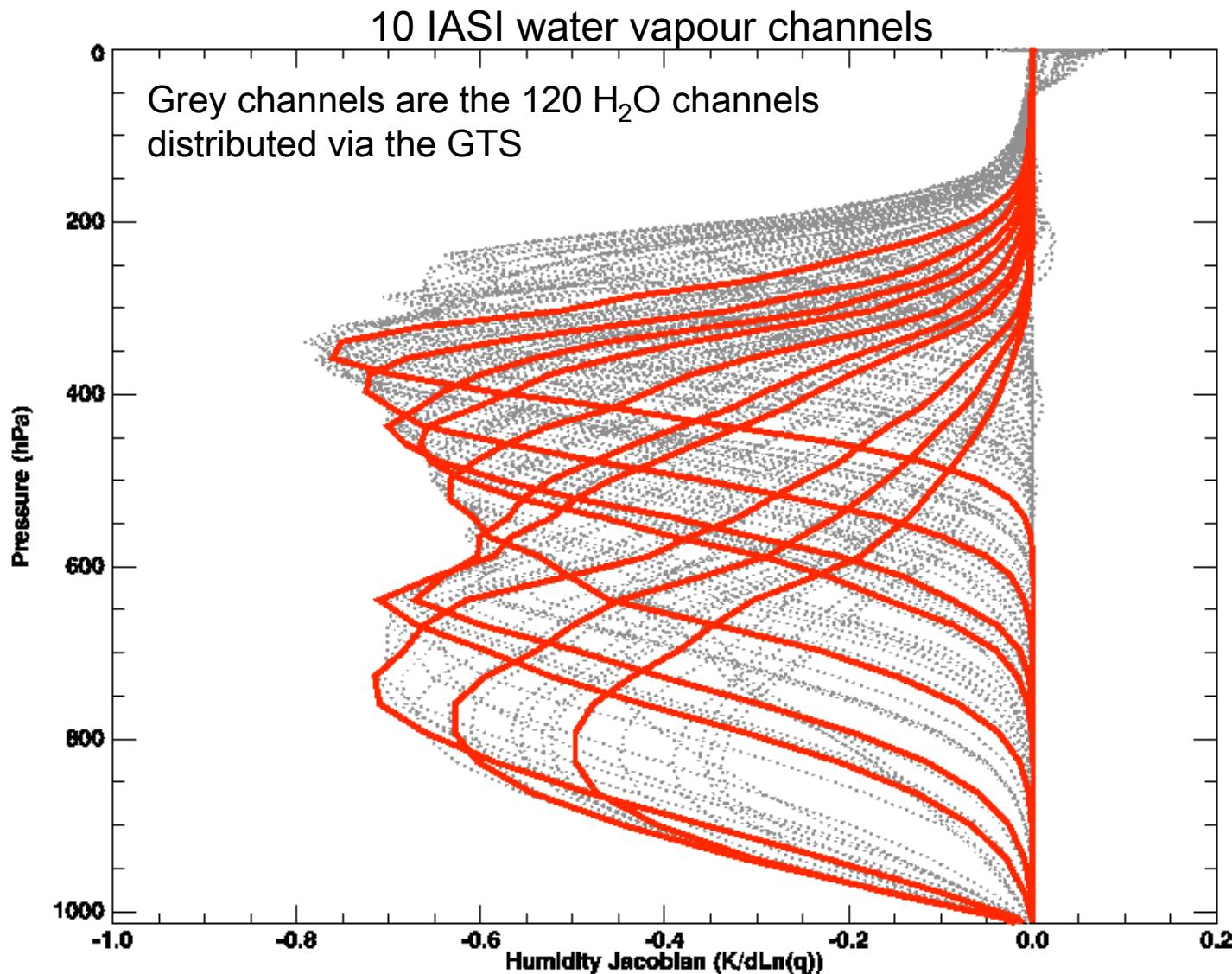
Upgrades: Addition of water vapour channels, cloud-affected radiances

Comprehensive observing system experiments

Future upgrades

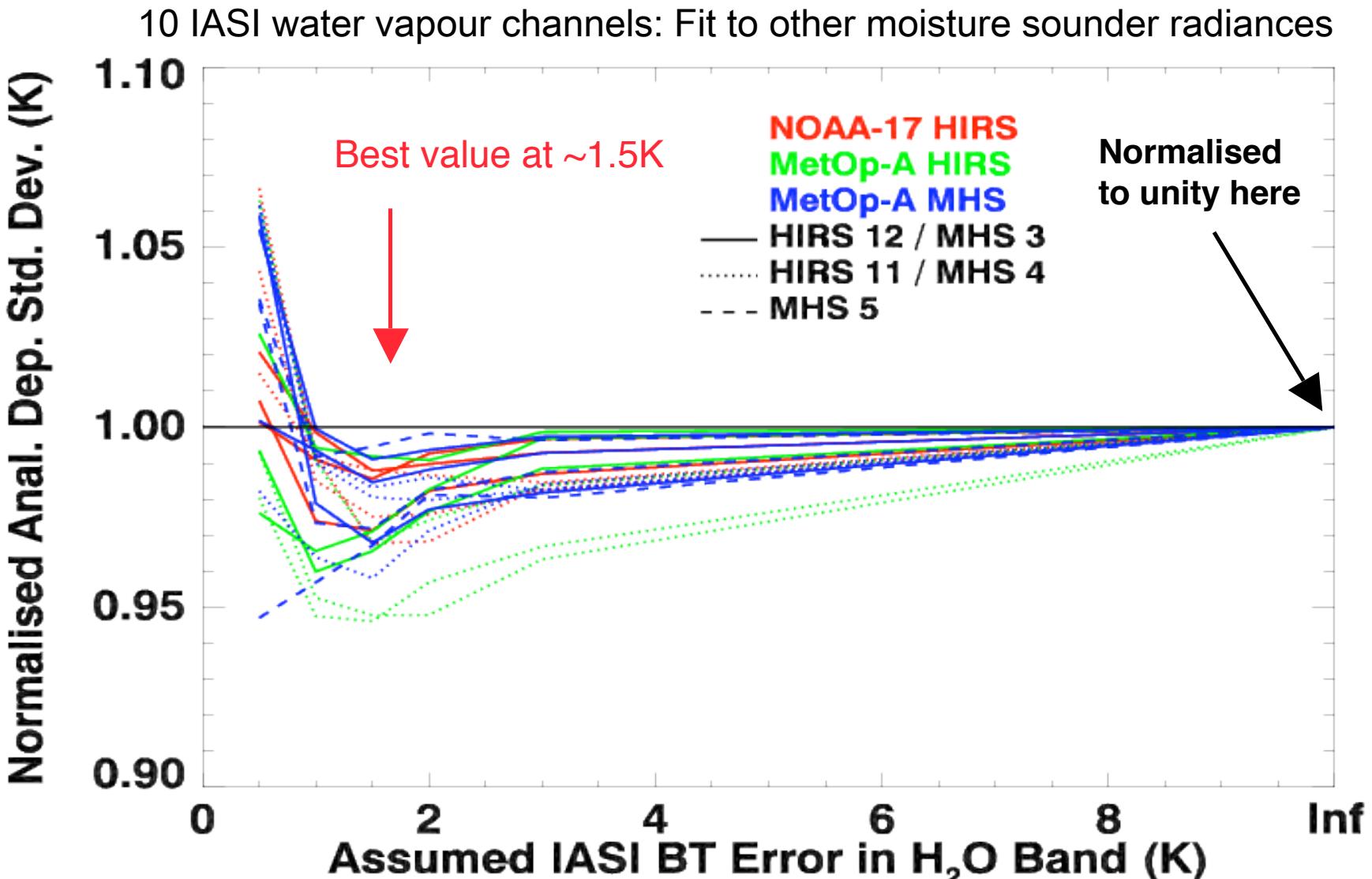
Summary

IASI H₂O channel impact



(A. Collard)

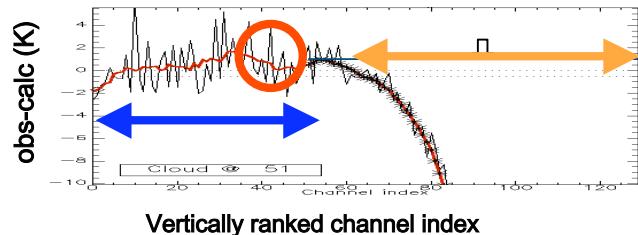
IASI H₂O channel impact



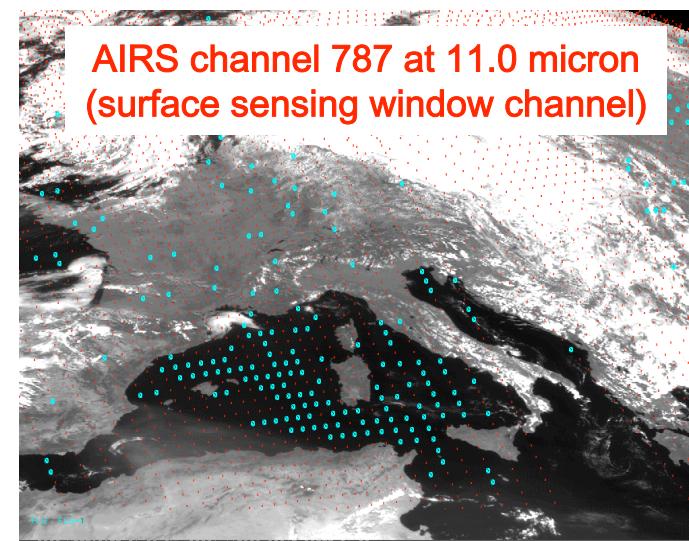
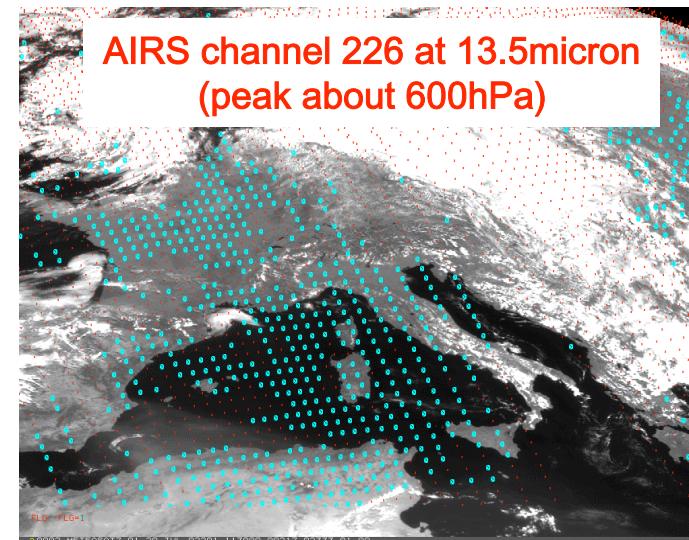
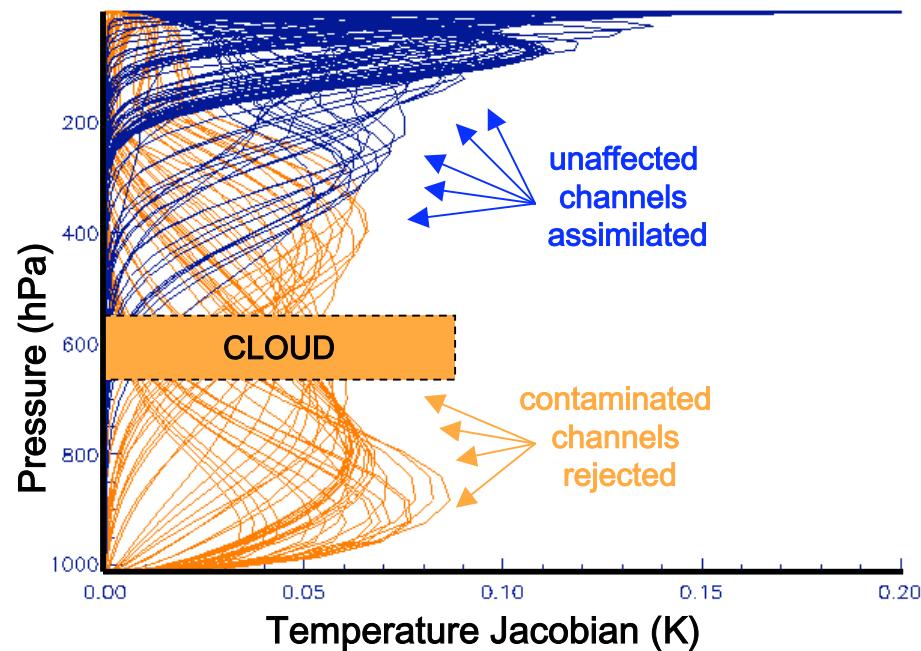
(A. Collard)

IASI/AIRS cloud detection

A non-linear pattern recognition algorithm is applied to departures of the observed radiance spectra from a computed clear-sky background spectra.



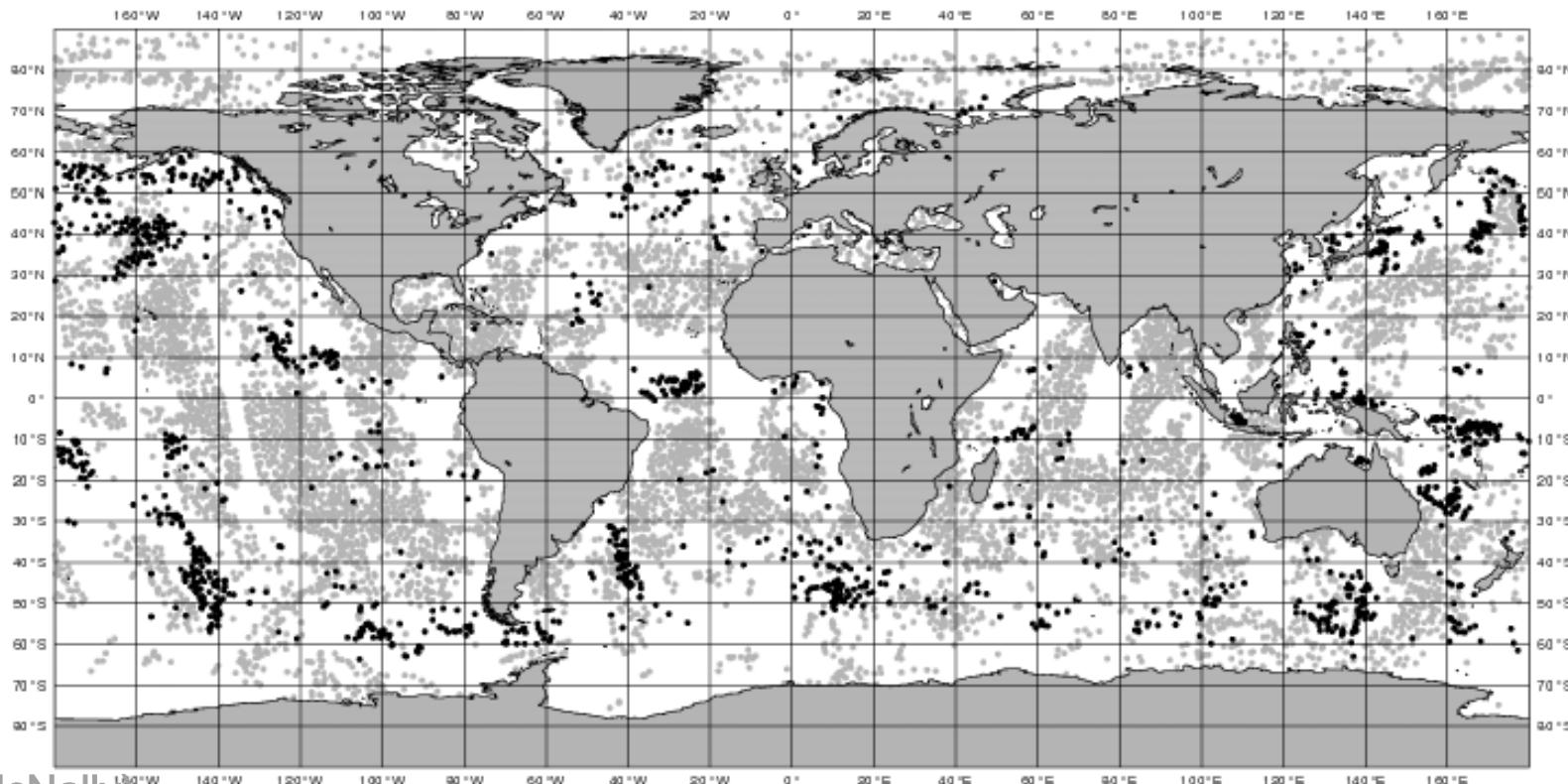
This identifies the characteristic signal of cloud in the data and allows contaminated channels to be rejected.



Assimilation of cloud-affected channels

- by adding cloud top pressure and effective cloud fraction to control vector (via sink variable), for retrieved effective cloud cover =1;
- no cloudy RT calculations required, conservative linearization point.

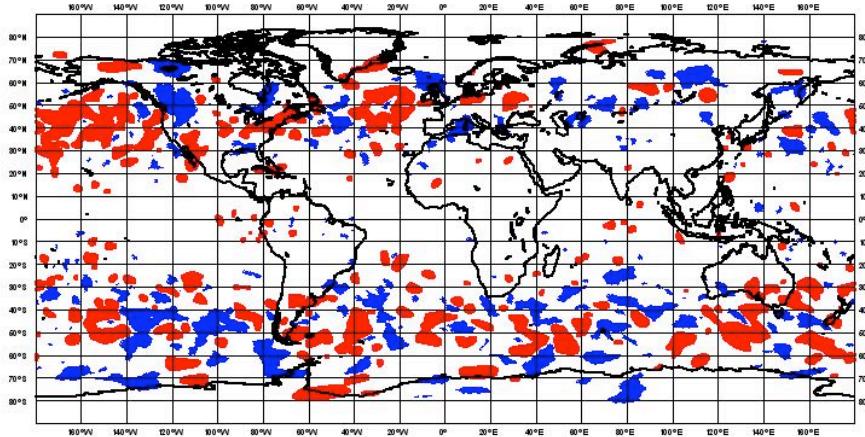
Single cycle HIRS, AIRS, IASI overcast / clear



(T. McNally)

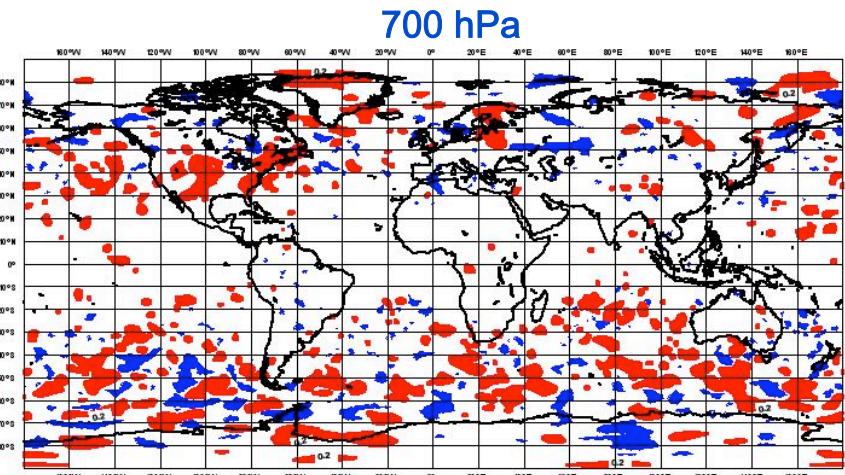
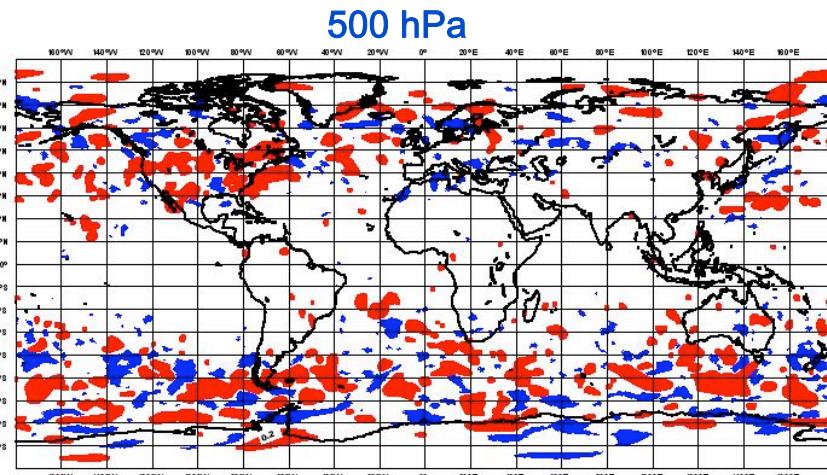
Assimilation of cloud-affected channels

Temperature forecast error RMSE difference
200 hPa (EXP-CTRL, 77 cases, own analyses)



Positive: deterioration
Negative: improvement

0.2+ K shading



(T. McNally)

Initial performance assessment

**Upgrades: Addition of water vapour
channels, cloud-affected radiances**

**Comprehensive observing system
experiments**

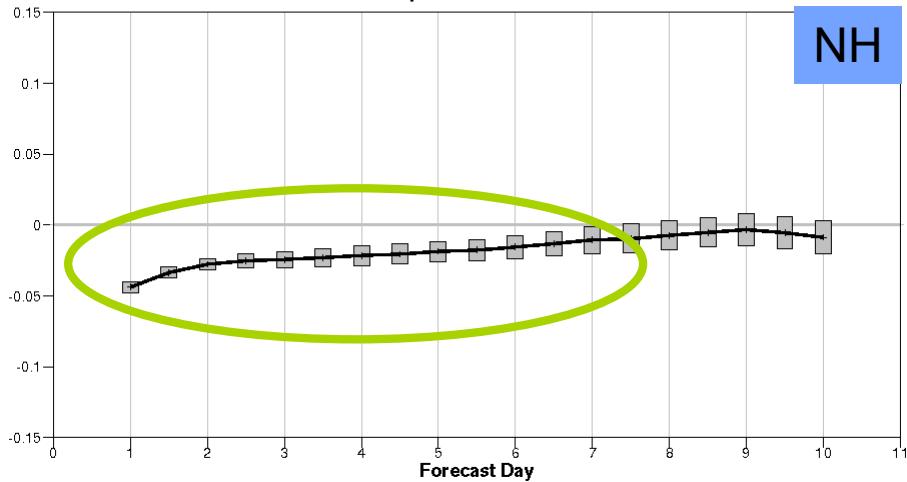
Future upgrades

Summary

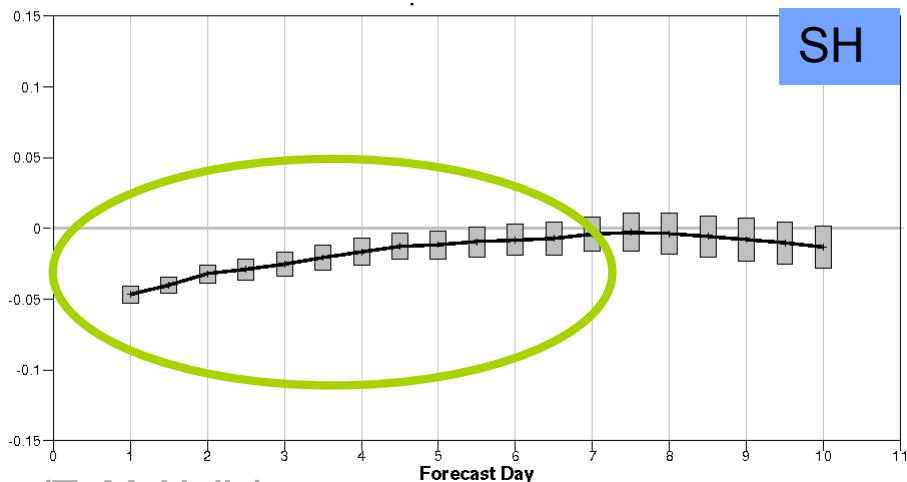
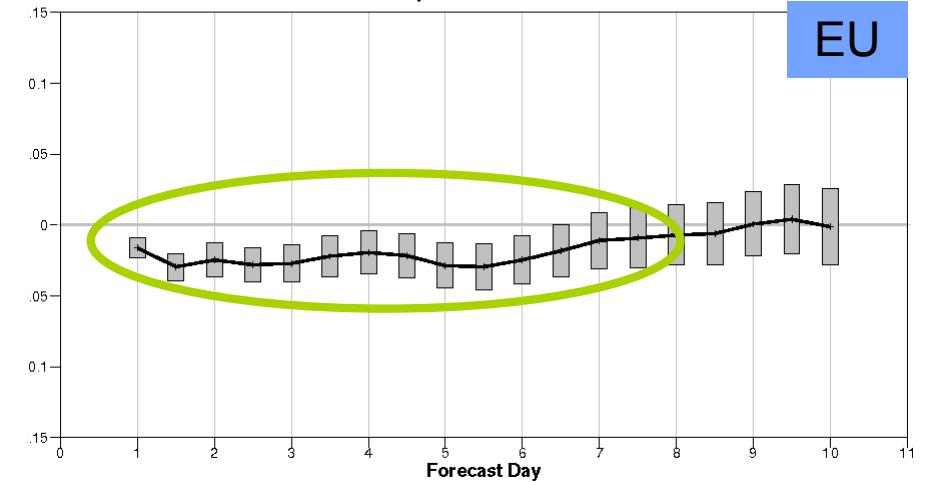
AIRS/IASI impact

control normalised f6bt minus f6c4
Root mean square error forecast
N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0
Date: 20080808 00UTC to 20090807 00UTC
500hPa Geopotential 00UTC
Confidence: 95%
Population: 365

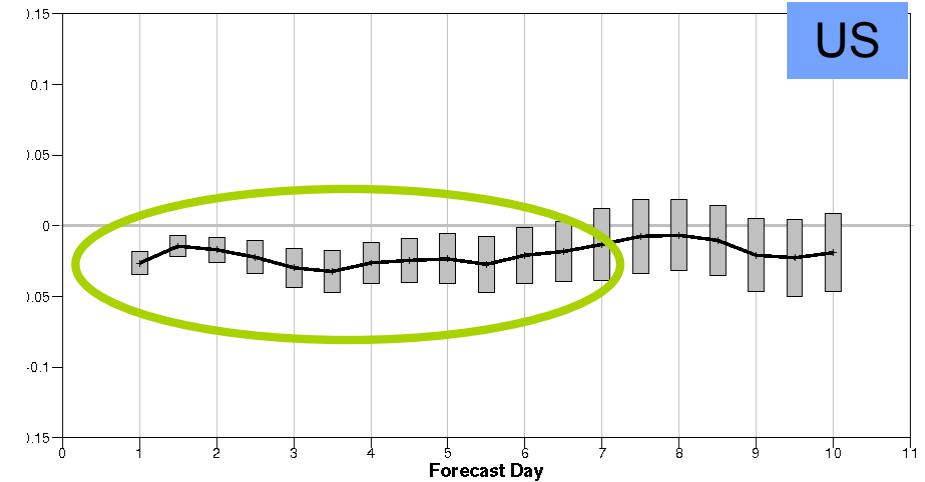
CTRL plus AIRS



control normalised f6bt minus f6c4
Root mean square error forecast
Europe Lat 35.0 to 75.0 Lon -12.5 to 42.5
Date: 20080808 00UTC to 20090807 00UTC
500hPa Geopotential 00UTC
Confidence: 95%
Population: 365



(T. McNally)

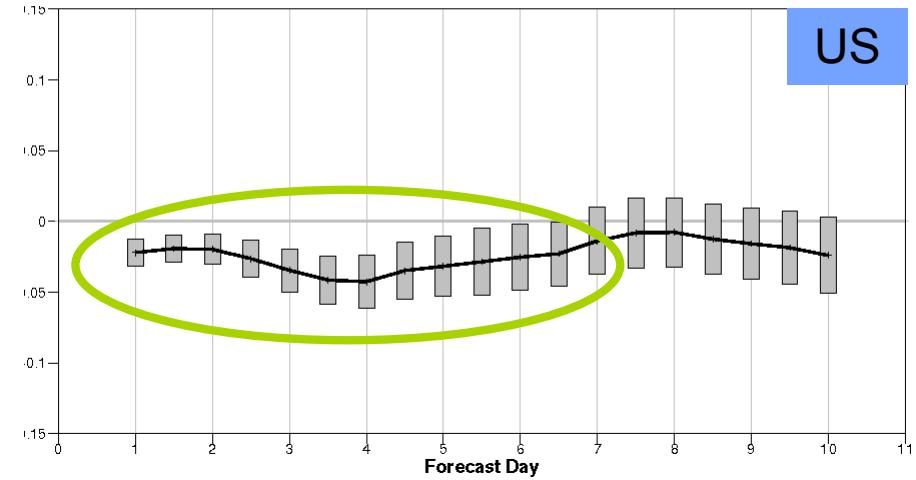
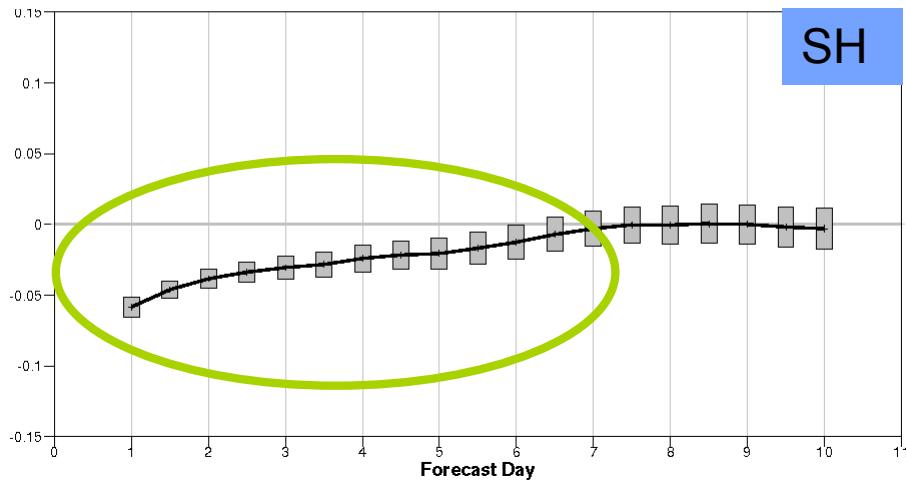
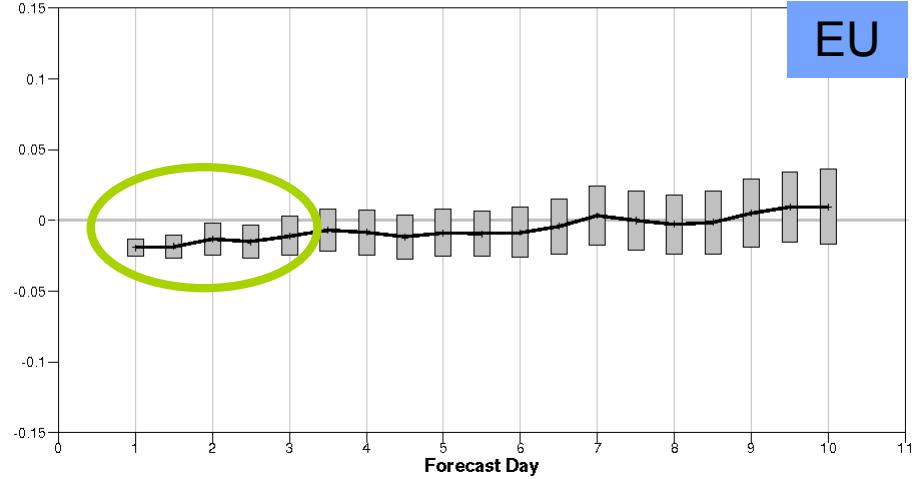
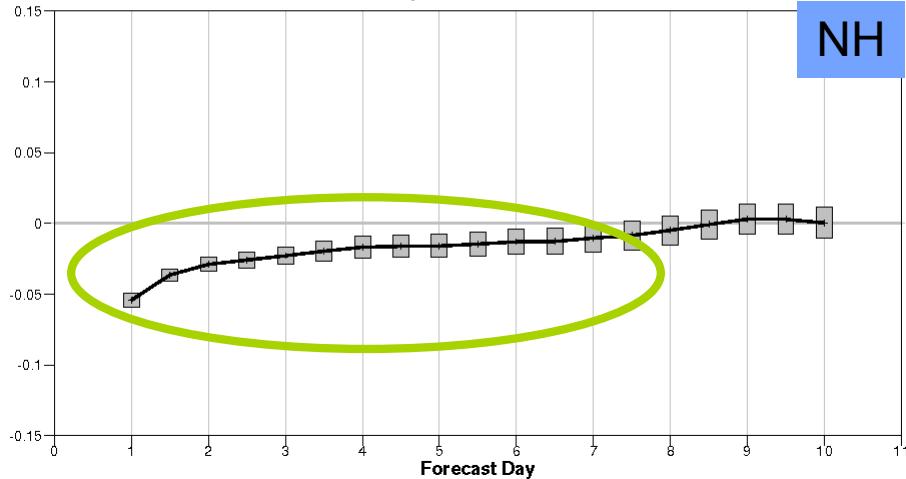


AIRS/IASI impact

control normalised f6fl minus f6c4
Root mean square error forecast
N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0
Date: 20080808 00UTC to 20090807 00UTC
500hPa Geopotential 00UTC
Confidence: 95%
Population: 365

control normalised f6fl minus f6c4
Root mean square error forecast
Europe Lat 35.0 to 75.0 Lon -12.5 to 42.5
Date: 20080808 00UTC to 20090807 00UTC
500hPa Geopotential 00UTC
Confidence: 95%
Population: 365

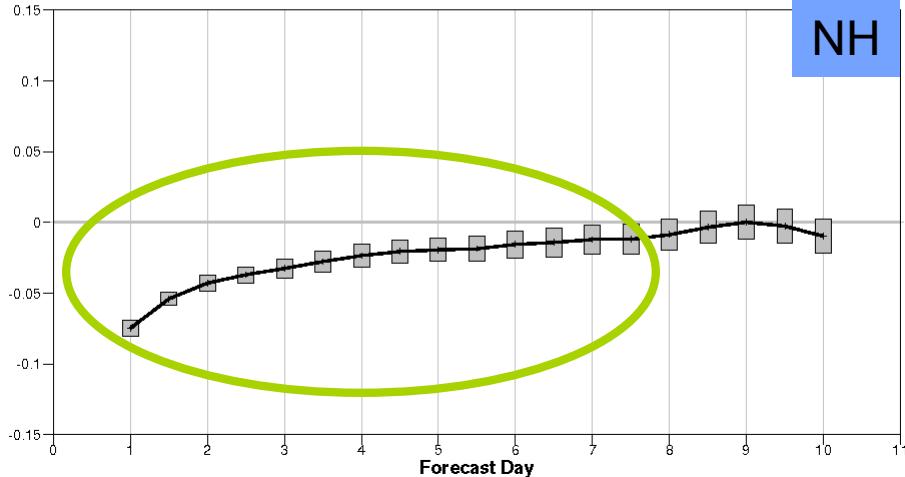
CTRL plus IASI



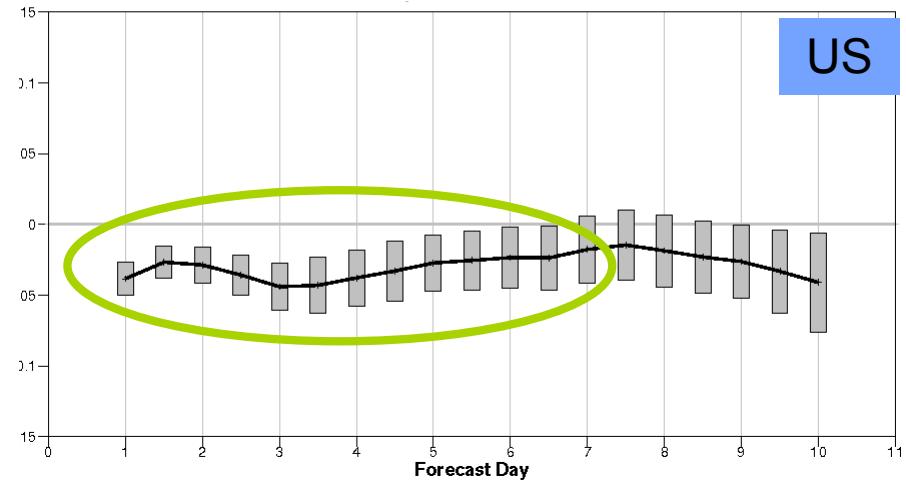
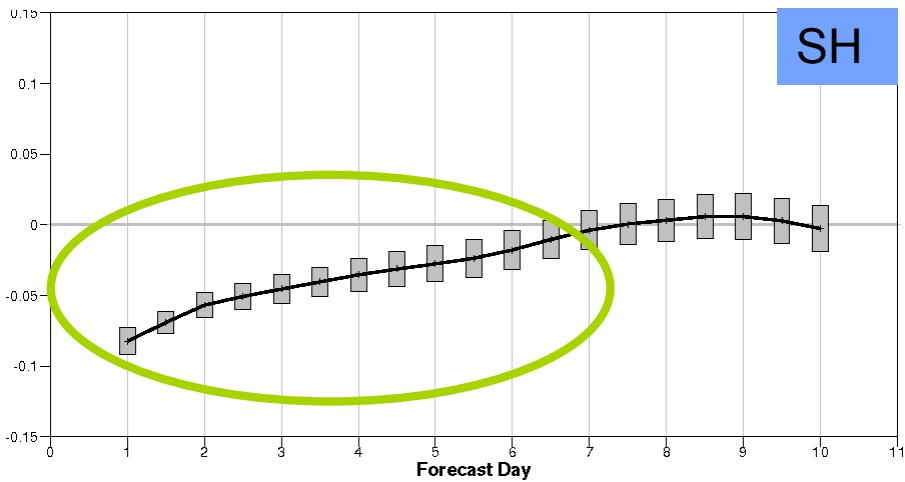
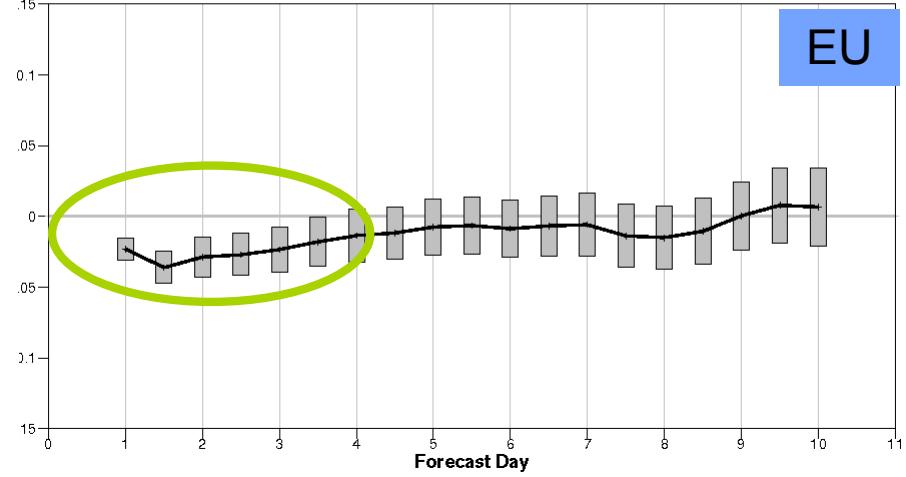
(T. McNally)

AIRS/IASI impact

control normalised f5li minus f6c4
 Root mean square error forecast
 N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0
 Date: 20080808 00UTC to 20090807 00UTC
 500hPa Geopotential 00UTC
 Confidence: 95%
 Population: 364

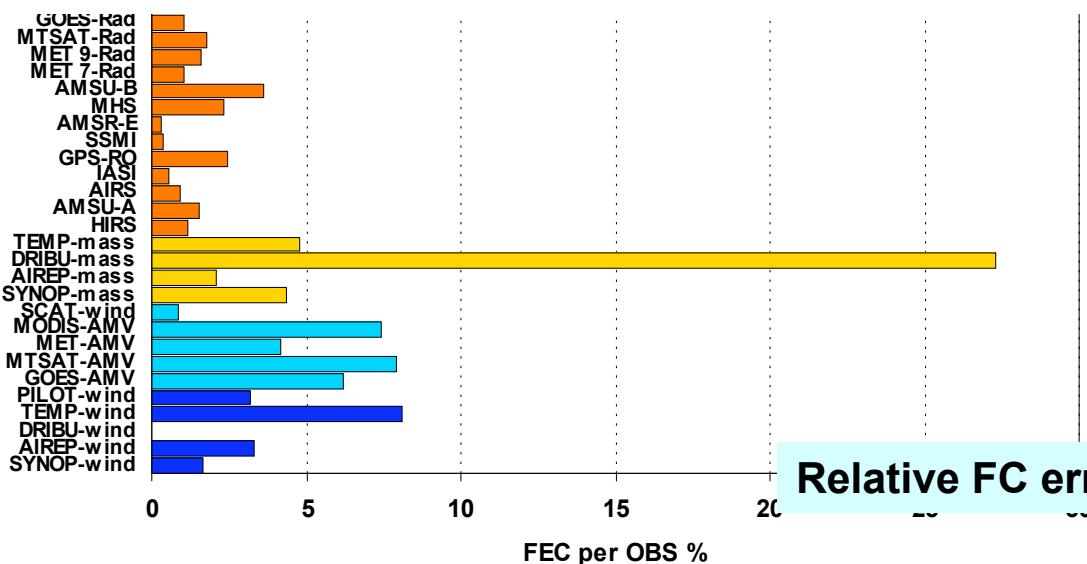
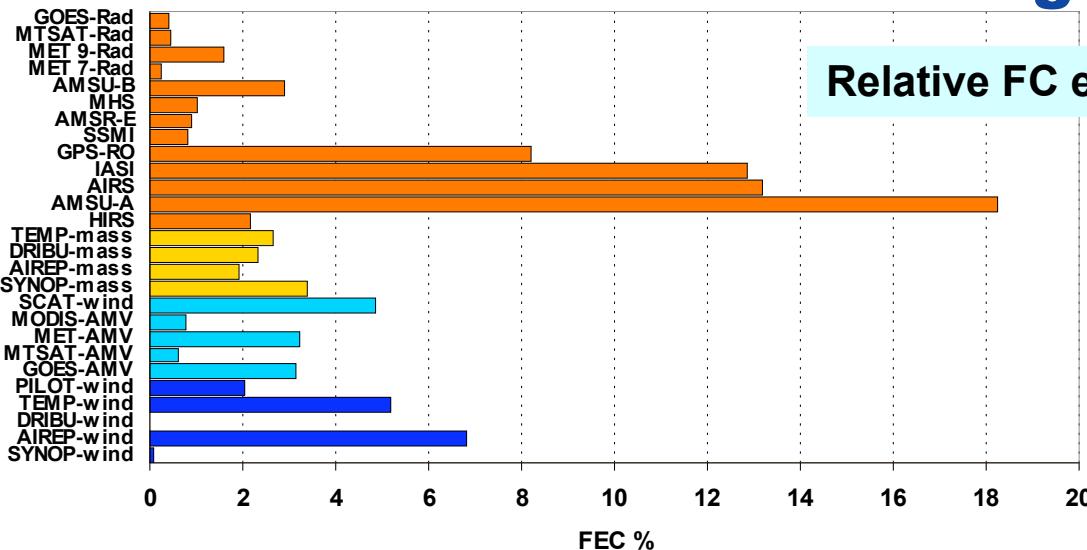


control normalised f5li minus f6c4
 Root mean square error forecast
 Europe Lat 35.0 to 75.0 Lon -12.5 to 42.5
 Date: 20080808 00UTC to 20090807 00UTC
 500hPa Geopotential 00UTC
 Confidence: 95%
 Population: 364



(T. McNally)

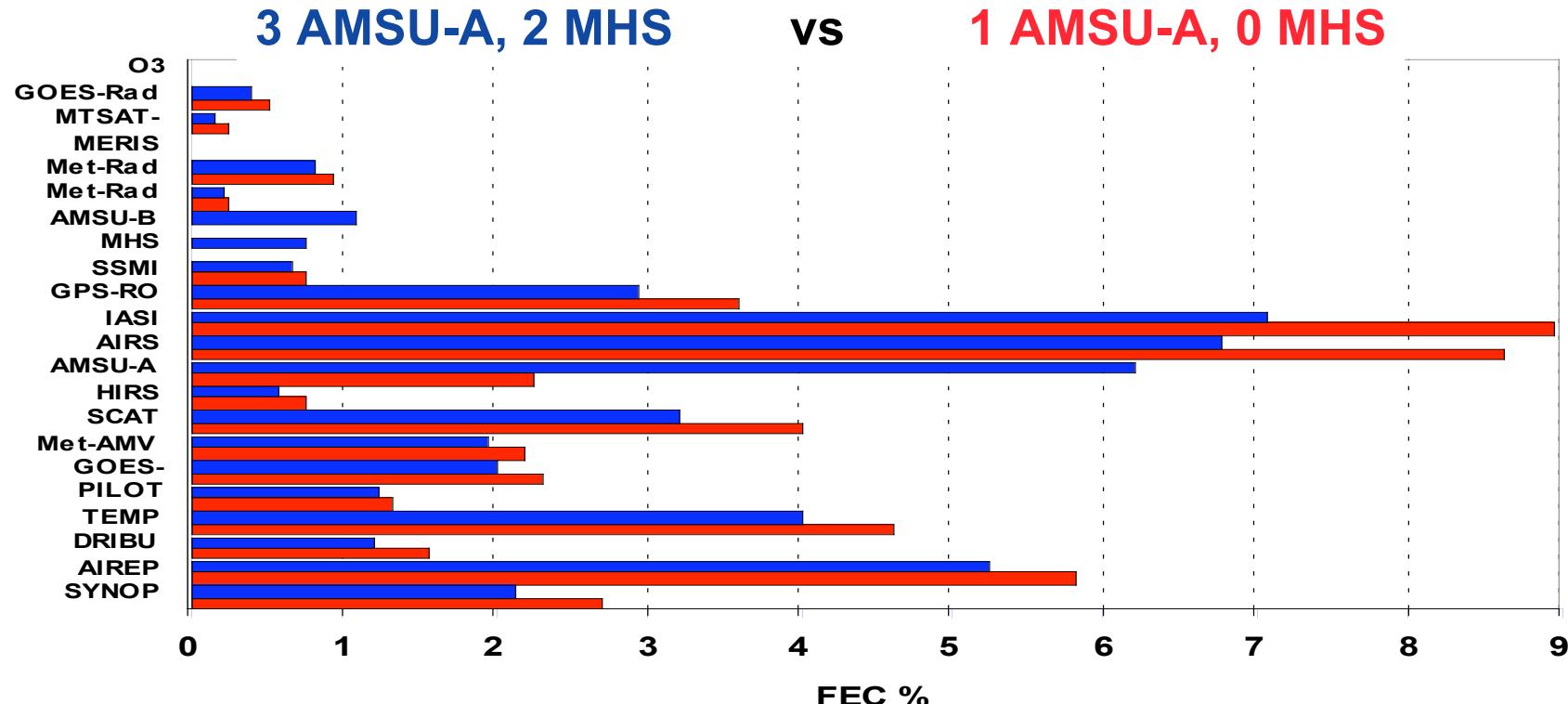
Advanced diagnostics



The *forecast sensitivity* (Cardinali, 2009, QJRMS, 135, 239-250) denotes the sensitivity of a forecast error metric (dry energy norm at 24 or 48-hour range) to the observations. The forecast sensitivity is determined by the sensitivity of the forecast error to the initial state, the innovation vector, and the Kalman gain.

(C. Cardinali)

Advanced diagnostics – MW sounder denial



Forecast error reduction [%]

(C. Cardinali)

Initial performance assessment

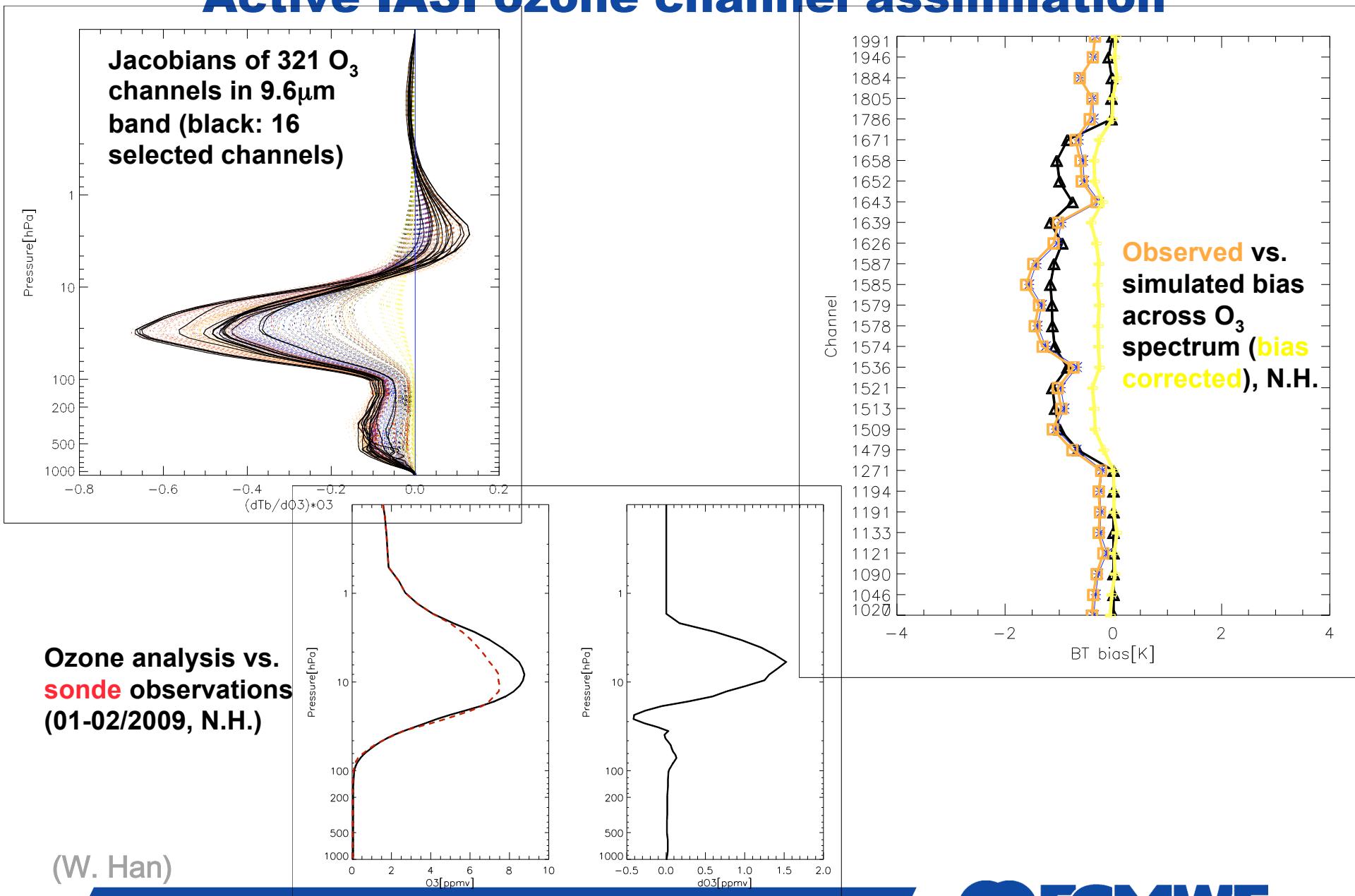
**Upgrades: Addition of water vapour
channels, cloud-affected radiances**

**Comprehensive observing system
experiments**

Future upgrades

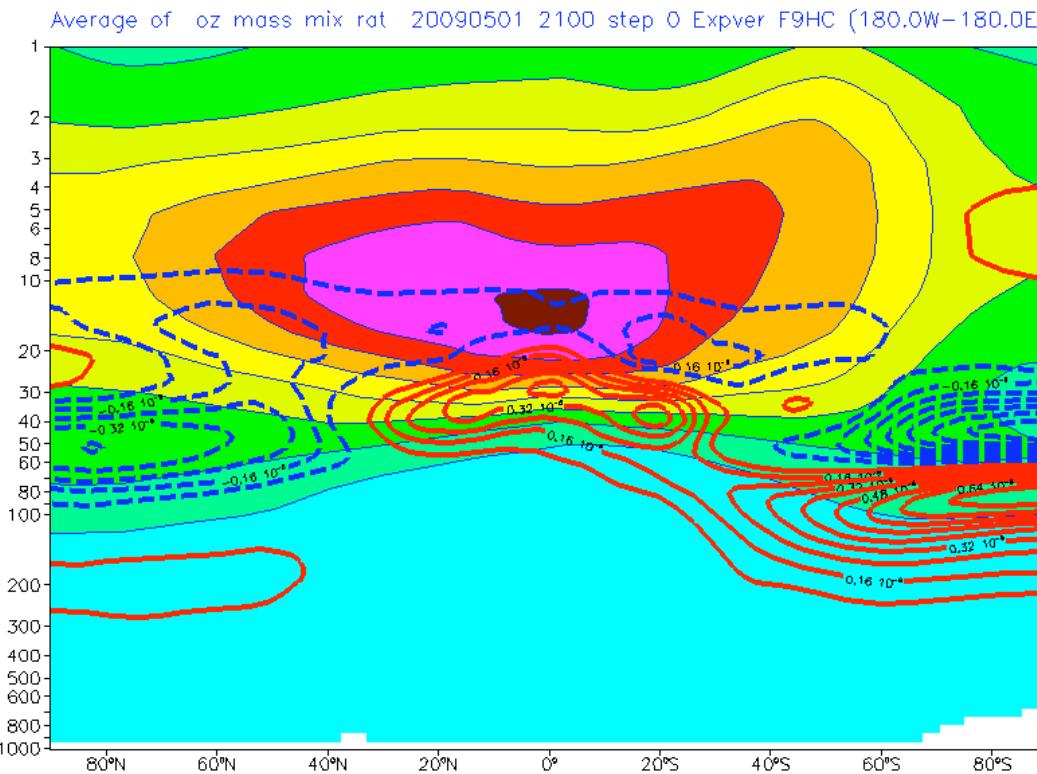
Summary

Active IASI ozone channel assimilation



IASI O₃-channels

- **Baseline System:** T511 (40 km) full operational data (no O₃ observations)
- **UV System:** As Baseline plus UV data from SBUV and OMI
- **IASI System:** As Baseline plus **16 IASI ozone channels** (LW cloud detection and channel 1585 anchored to **zero bias correction**, other channels VarBC)

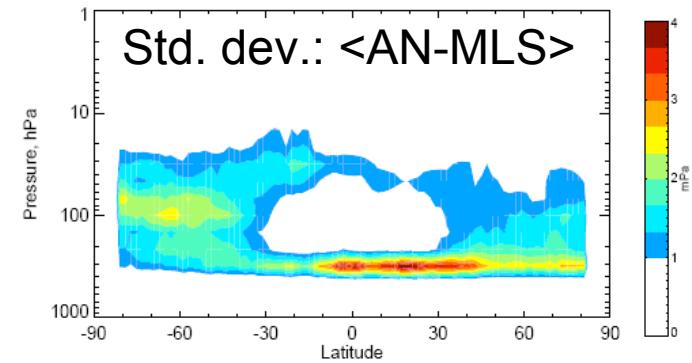
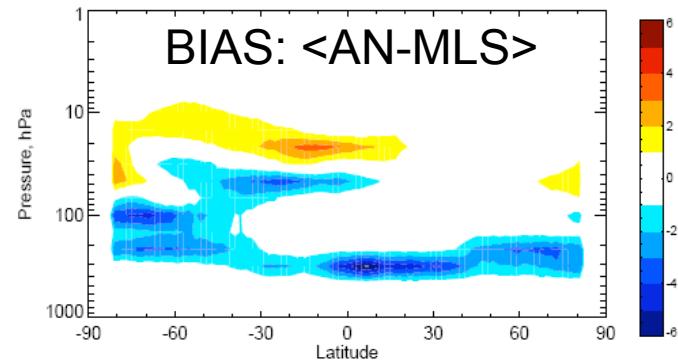


Zonal mean cross section of full ozone field (shaded) and mean analysis difference with and without IASI ozone channels (units are mass mixing ratio)

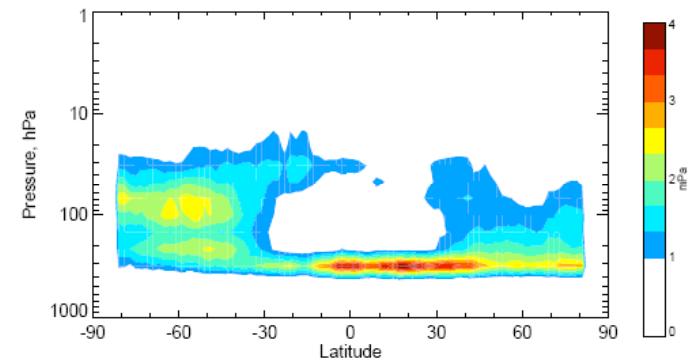
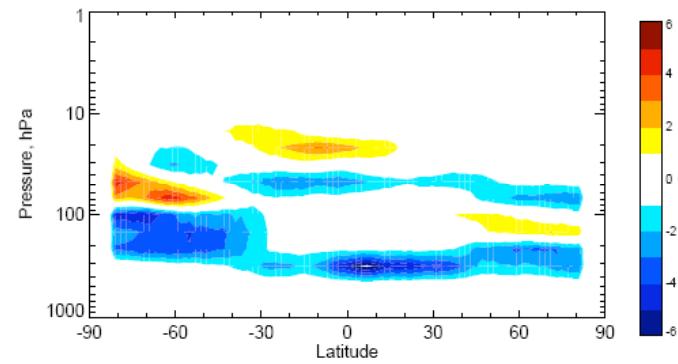
Verification against MLS

(2 weeks, 20090615-20090630)

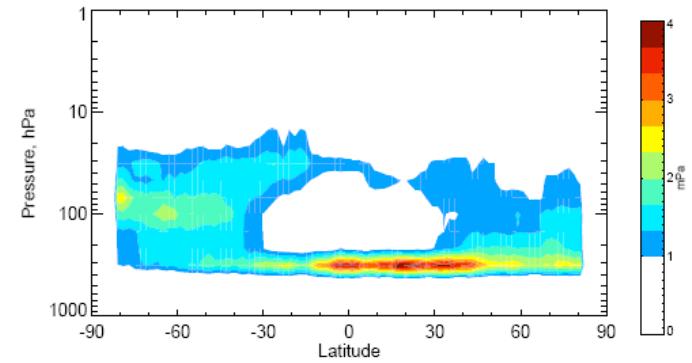
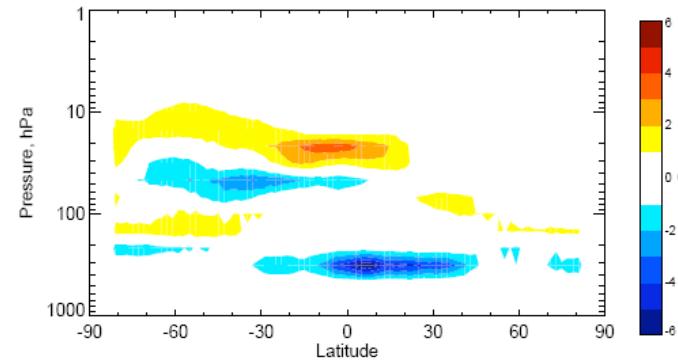
BASELINE = No O_3
Observations



BASELINE
+ SBUV + OMI

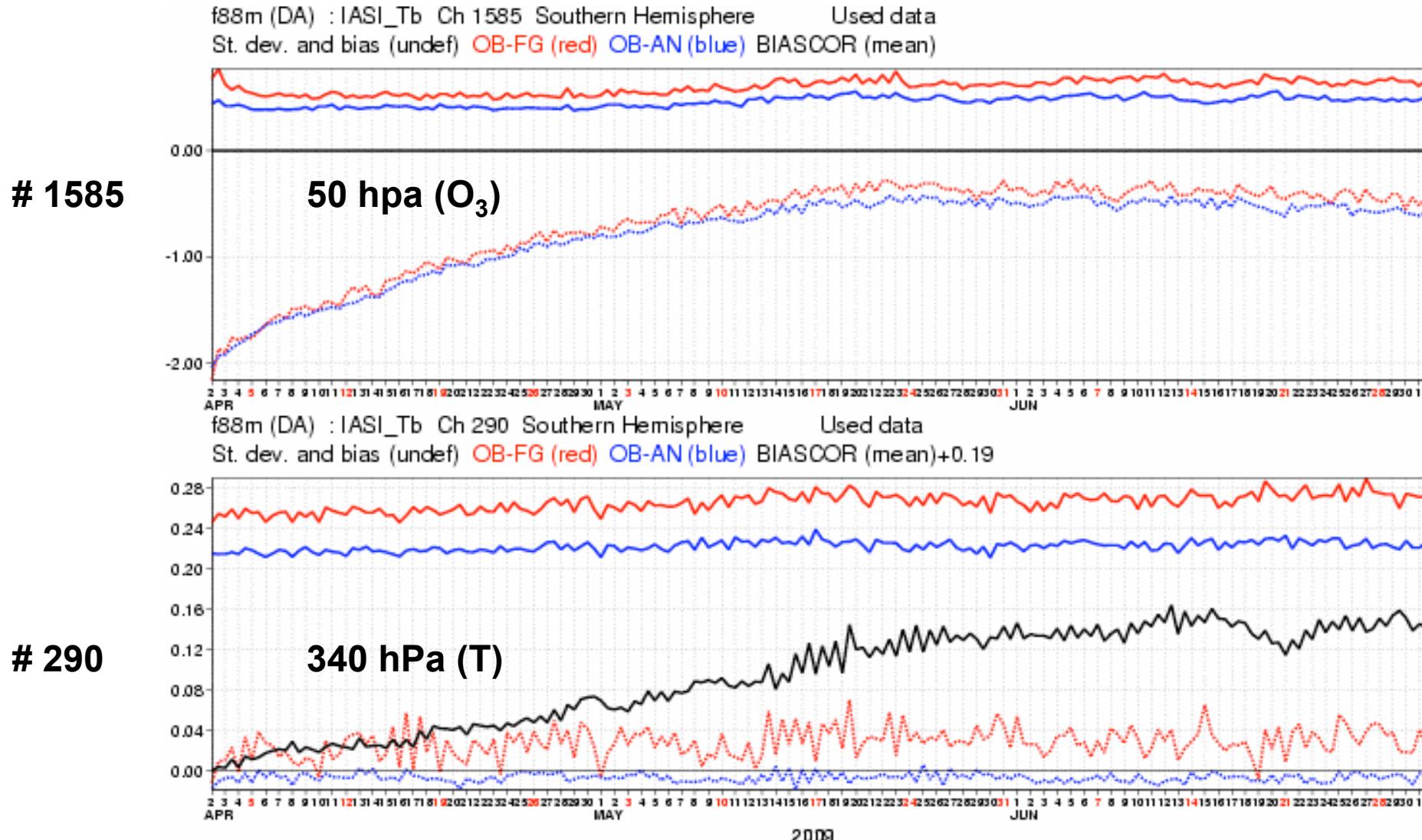


BASELINE
+ IASI 16 O_3
channels
(W. Han)



Impact on T-channels with O₃-sensitivity

Experiment with anchoring channel 1585 and 15 bias-corrected channels

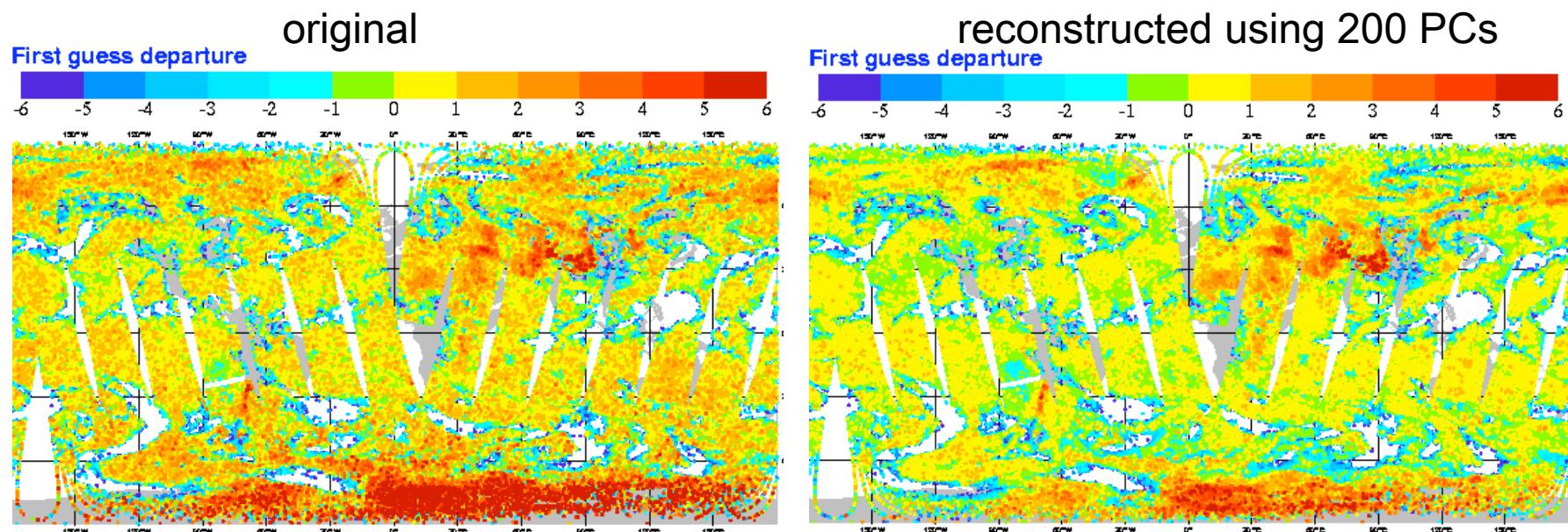


IASI data compression

Objective:

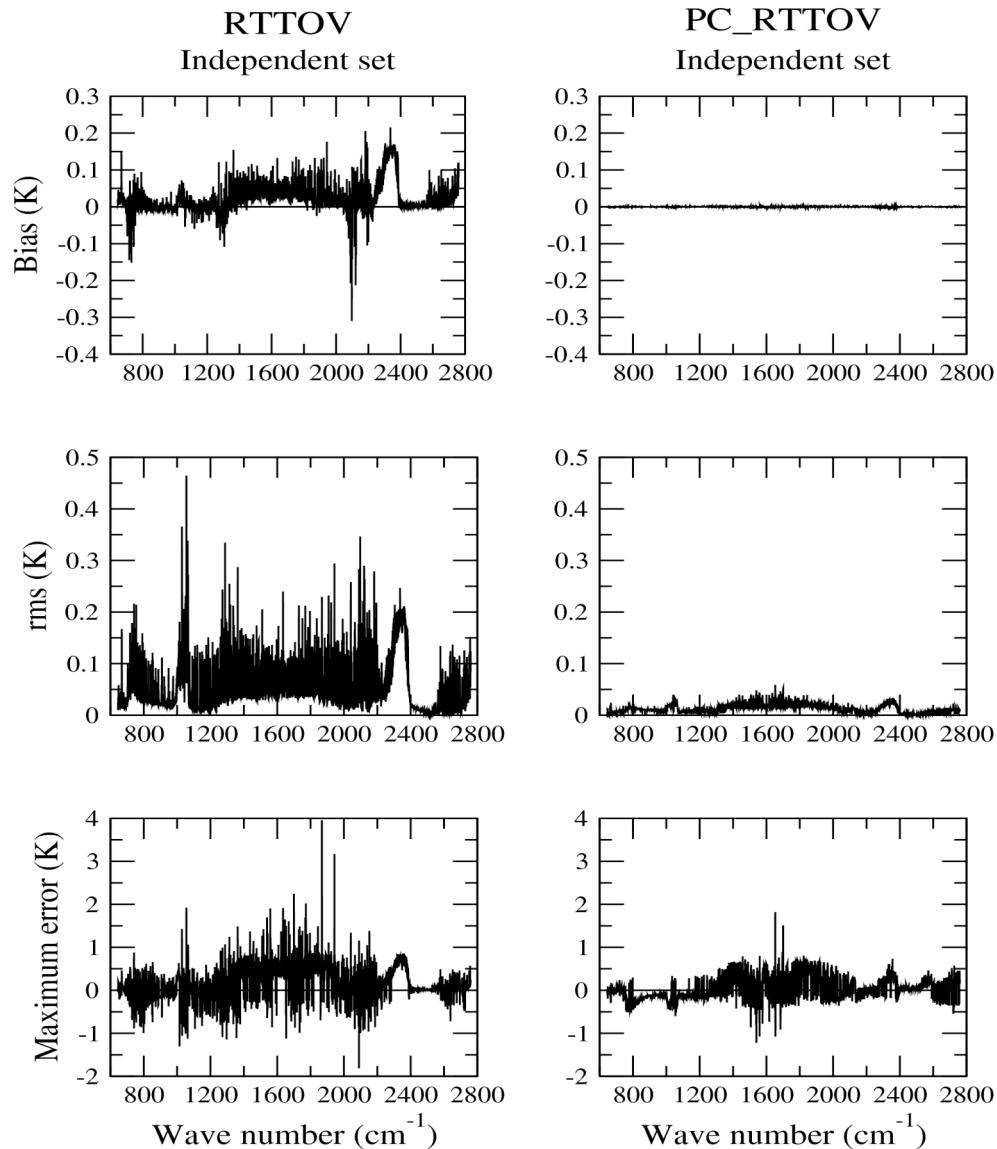
- Development of PC radiative transfer model to be able to assimilate PC-score compressed data from advanced infrared sounders.
- Evaluate model with focus on shortwave IASI channels and the potential of efficient noise reduction.

IASI channel 6982 at 4.2 μm



(A. Collard)

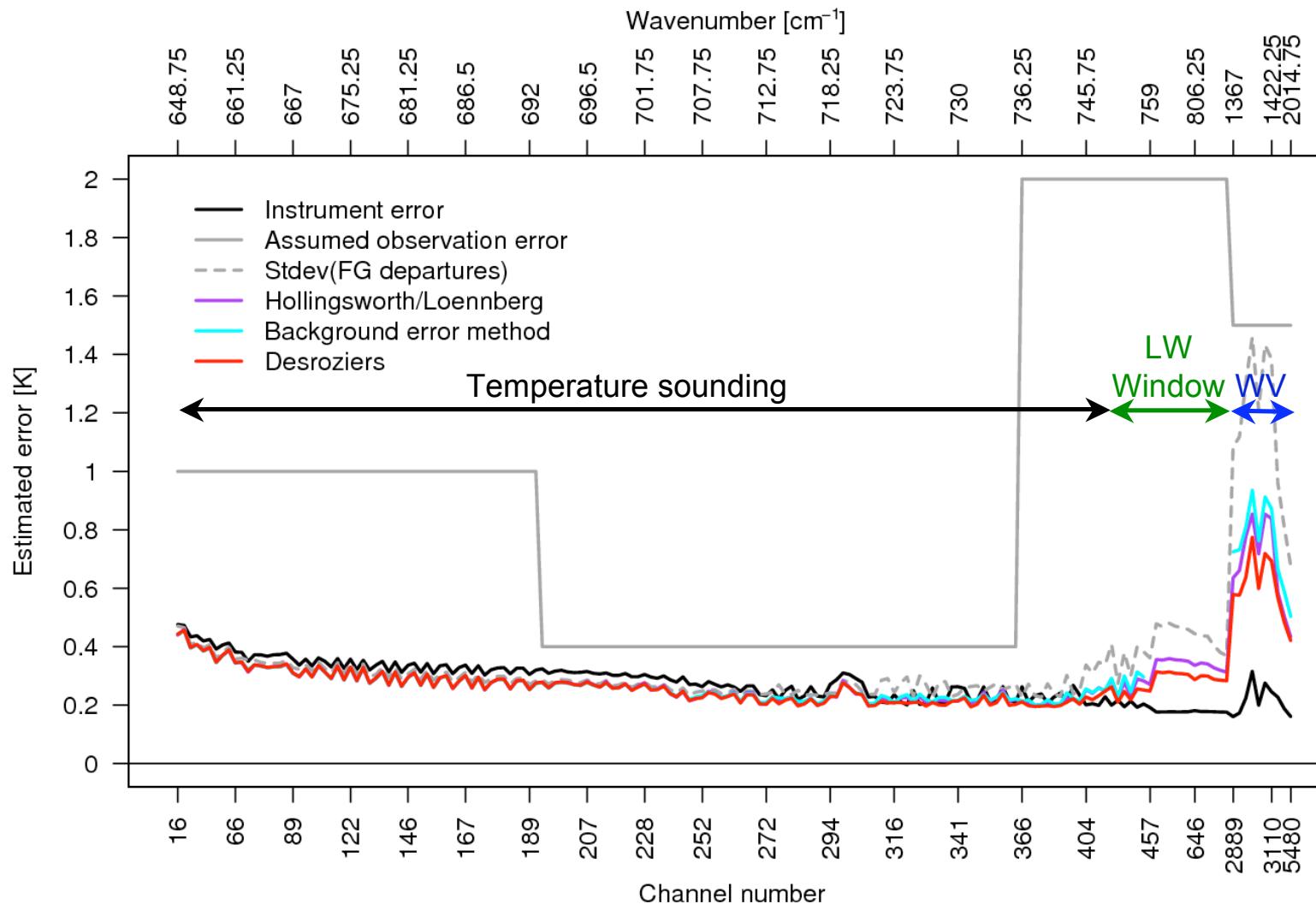
Accuracy of PC radiative transfer



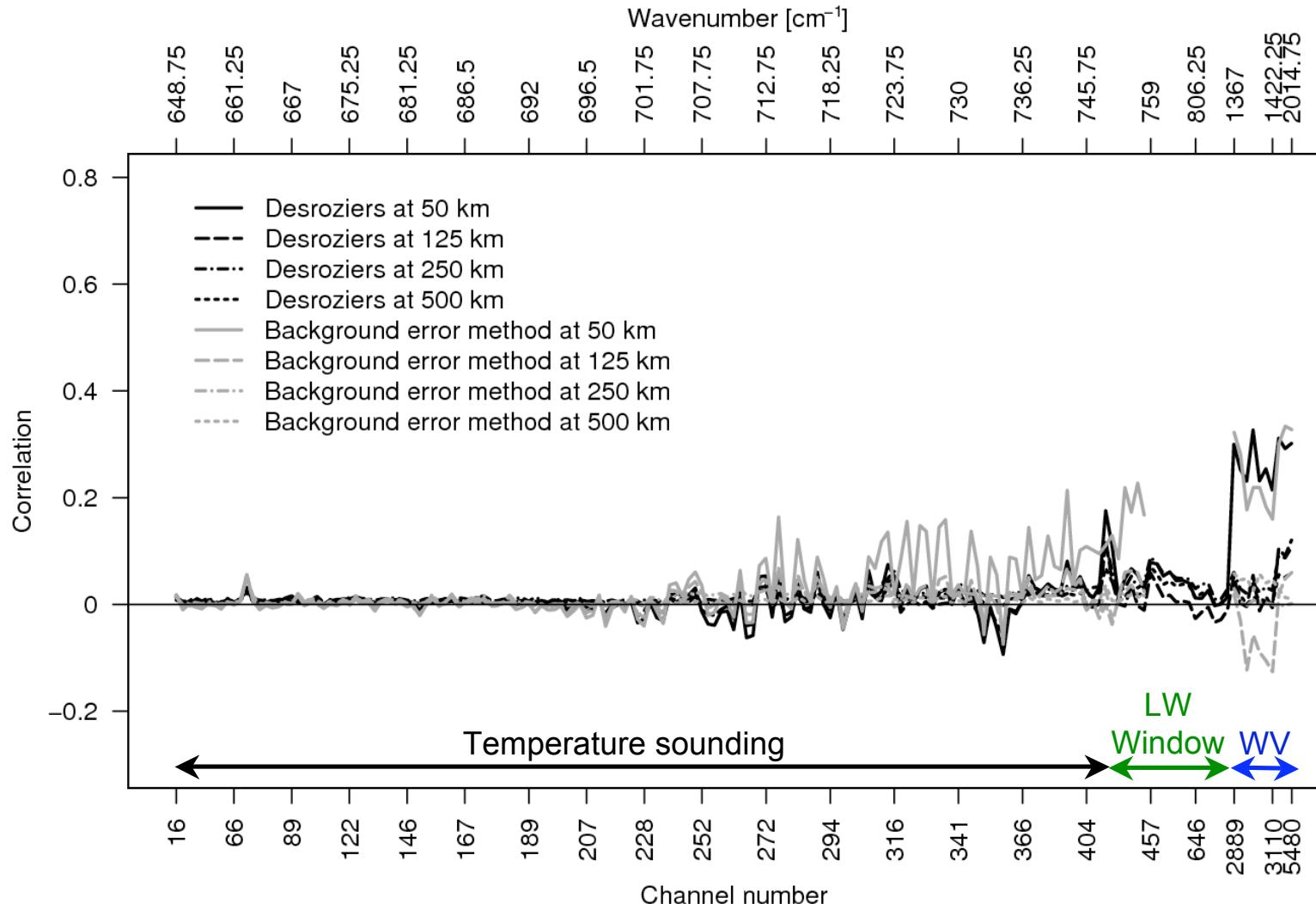
Fit of RTTOV and PC_RTTOV
(400 PCs, 600 predictors) to
line-by-line radiances for a
5165 profile independent set

... and the latest ...

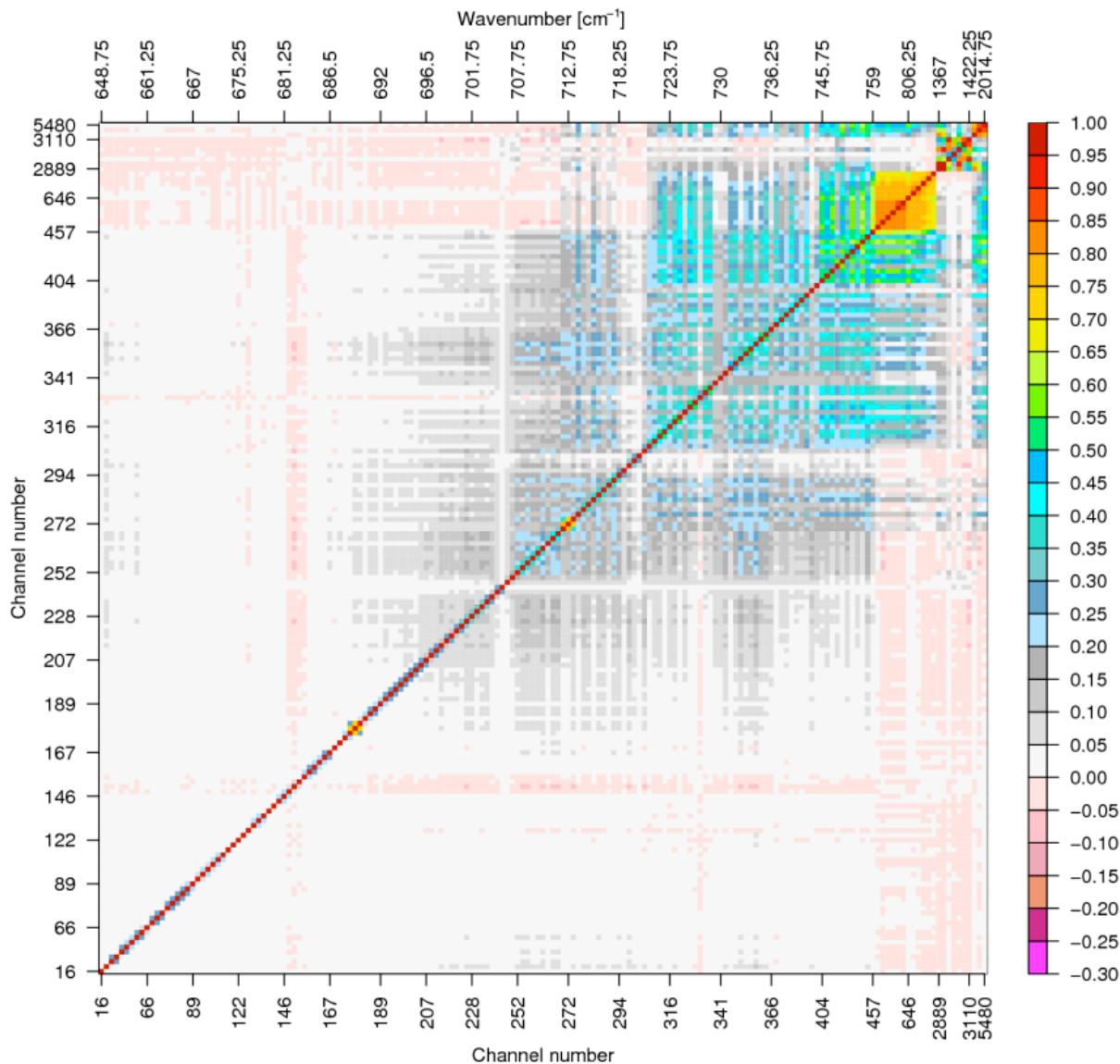
IASI: Observation errors (σ_o)



IASI: Spatial error correlations

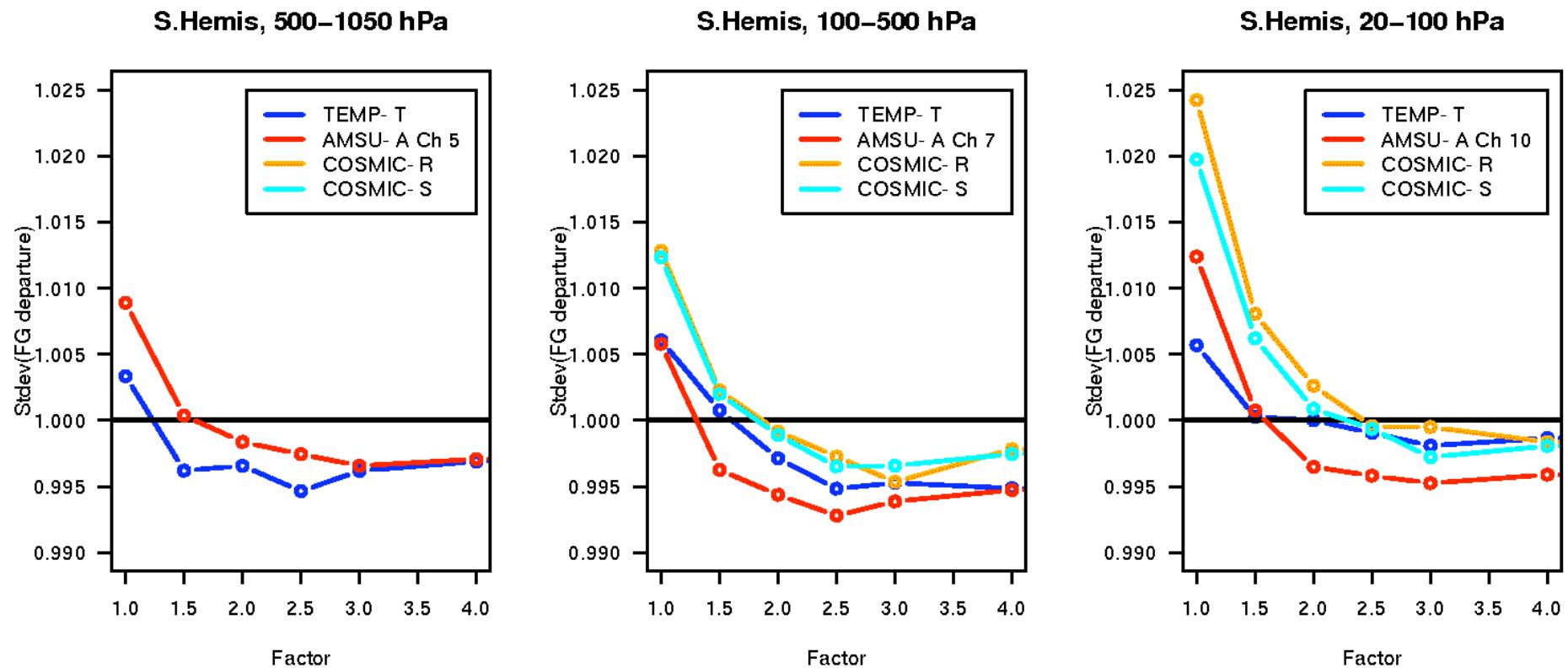


IASI: Inter-channel error correlations (Desroziers)



4D-Var experiments

- Use Desroziers-estimated observation errors in 4DVAR, with correlations, and scaling factor (July/August 2009).
- Standard deviations of Obs-FG, normalised to 1 for no-IASI experiment:

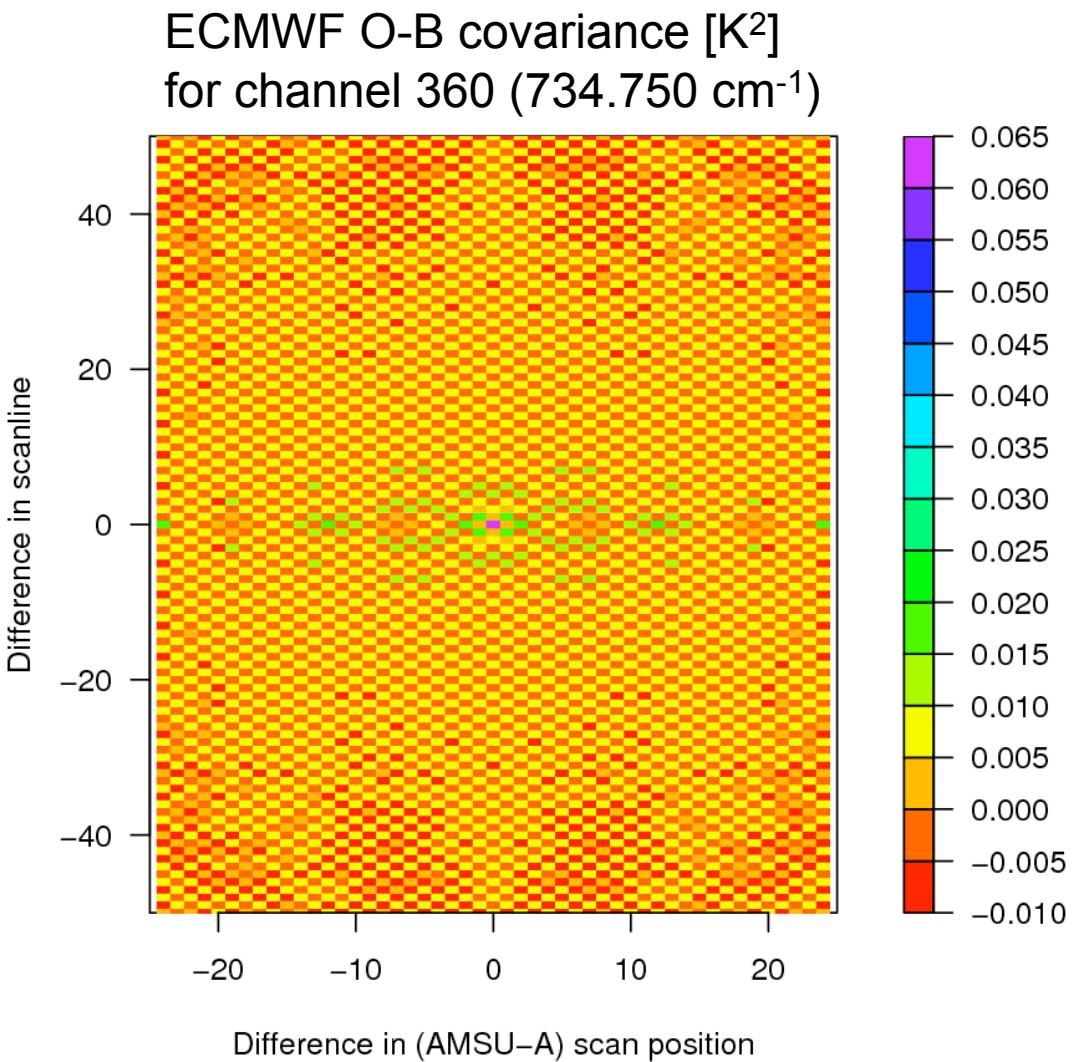
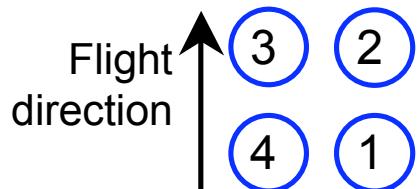


IASI Pixel 1 spatial covariance

Chessboard pattern apparent in background departure covariances for almost all assimilated IASI channels.

Pixel numbering:

At ECMWF: Only pixel 1 of 4 IASI pixels within AMSU-A FOV is currently considered.



(N. Bormann)

Initial performance assessment

**Upgrades: Addition of water vapour
channels, cloud-affected radiances**

**Comprehensive observing system
experiments**

Future upgrades

Summary

Summary

Advanced sounders (AIRS/IASI) represent the most valuable single instrument type for NWP

Ideally, AIRS/IASI observations are complemented by passive microwave (clouds/precipitation), conventional and radio occultation observations (anchoring of bias correction)

At ECMWF, IASI observation usage has been constantly improved/extended since initial implementation on 12 June 2007: Cloud detection, quality control, water vapour channels, cloud-affected radiances

Next developments:

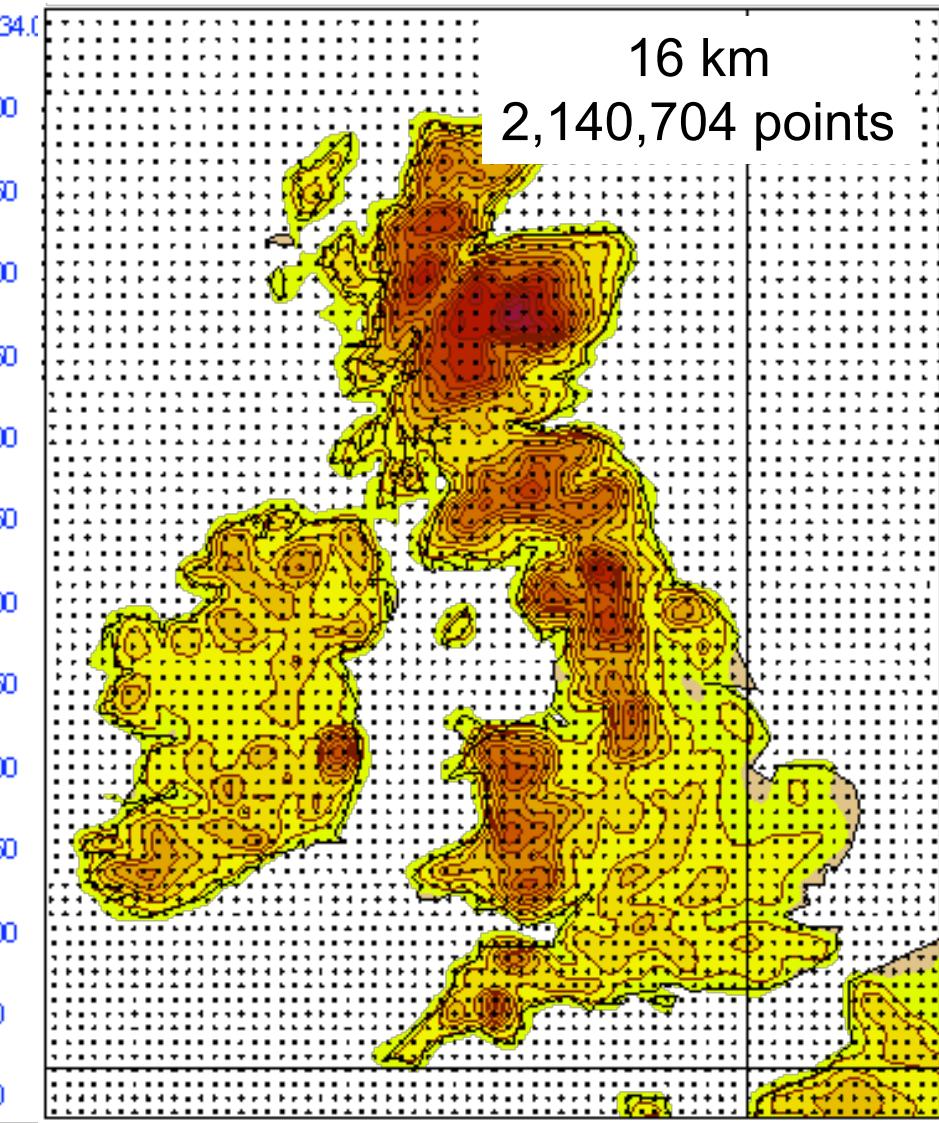
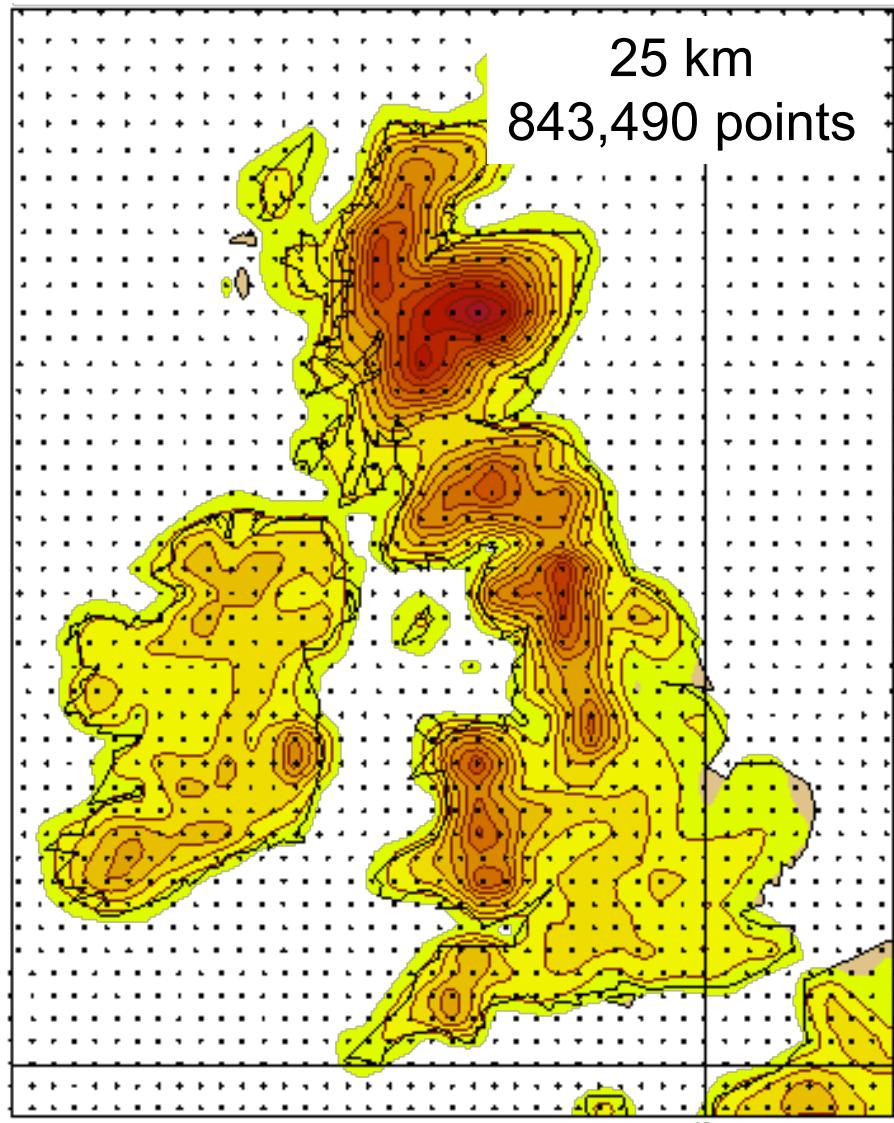
- Usage over land, improved usage over sea-ice
- More aggressive usage of cloud-affected channels
- Active usage of ozone channels
- Test of Principal Component model with real observations for IASI band 3 (and full spectrum)
- Inclusion of variable CO₂ (and other trace gases)

IASI spatial covariance - summary

- Background departure covariances for IASI suggest a small error that is correlated between different scan-positions and scan-lines, with alternating positive and negative correlations.
- Similar patterns observed at ECMWF and Met Office.
- Effect largest for pixels 1 and 2, little effect for pixels 3 and 4.
- The size of the error is small and of no concern to the assimilation of the data.

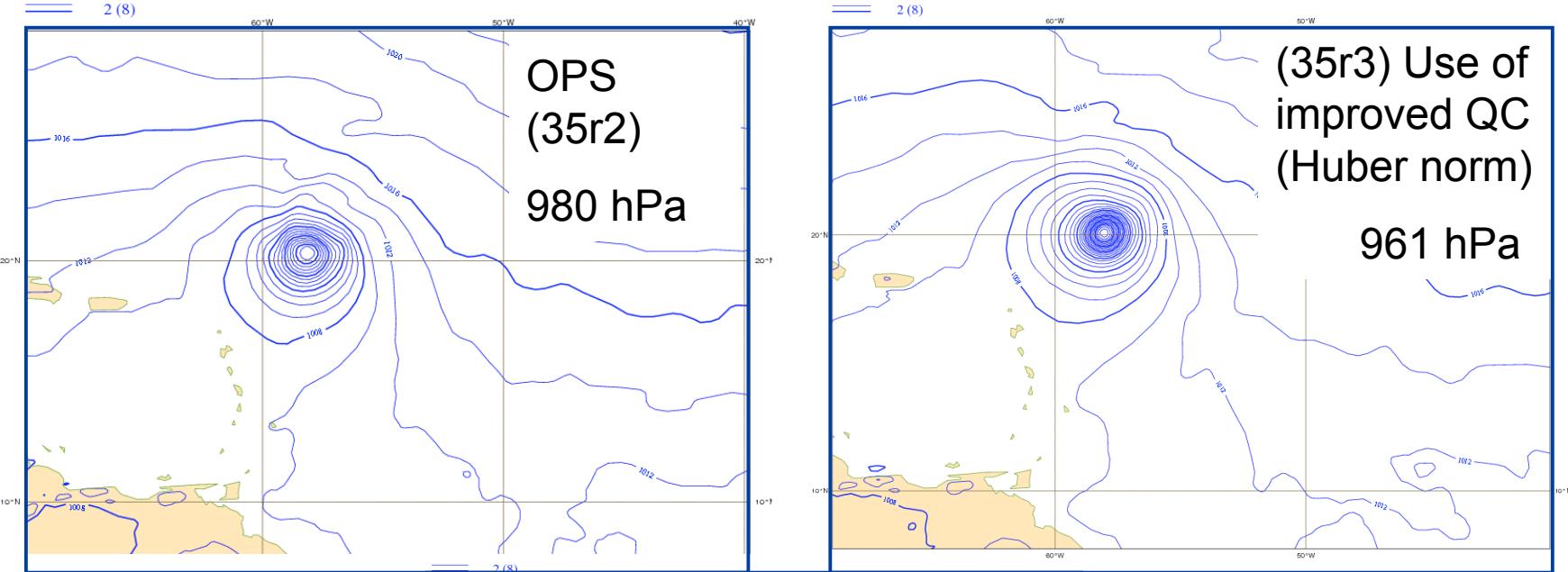
- Error appears to be correlated to the direction of the movement of the corner-cube mirror.
- Possibly a signature of micro-vibrations affecting spectral characteristics (Denis Blumstein)?

Model grids for T799 and T1279

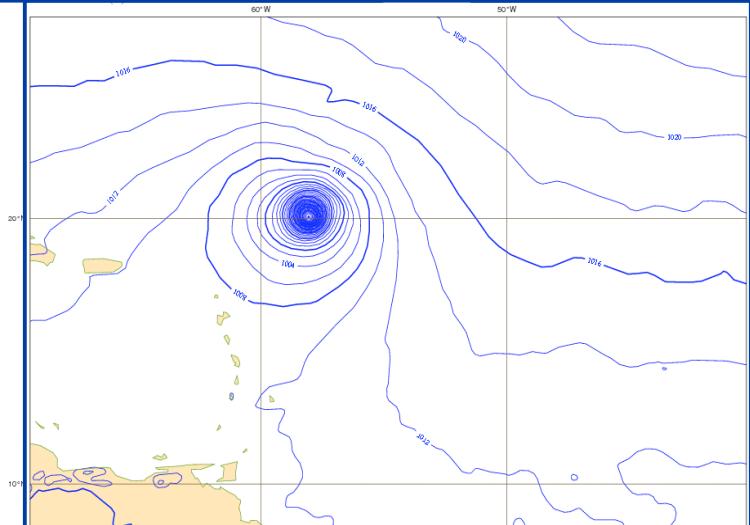


T1279 Tropical cyclone analyses improved

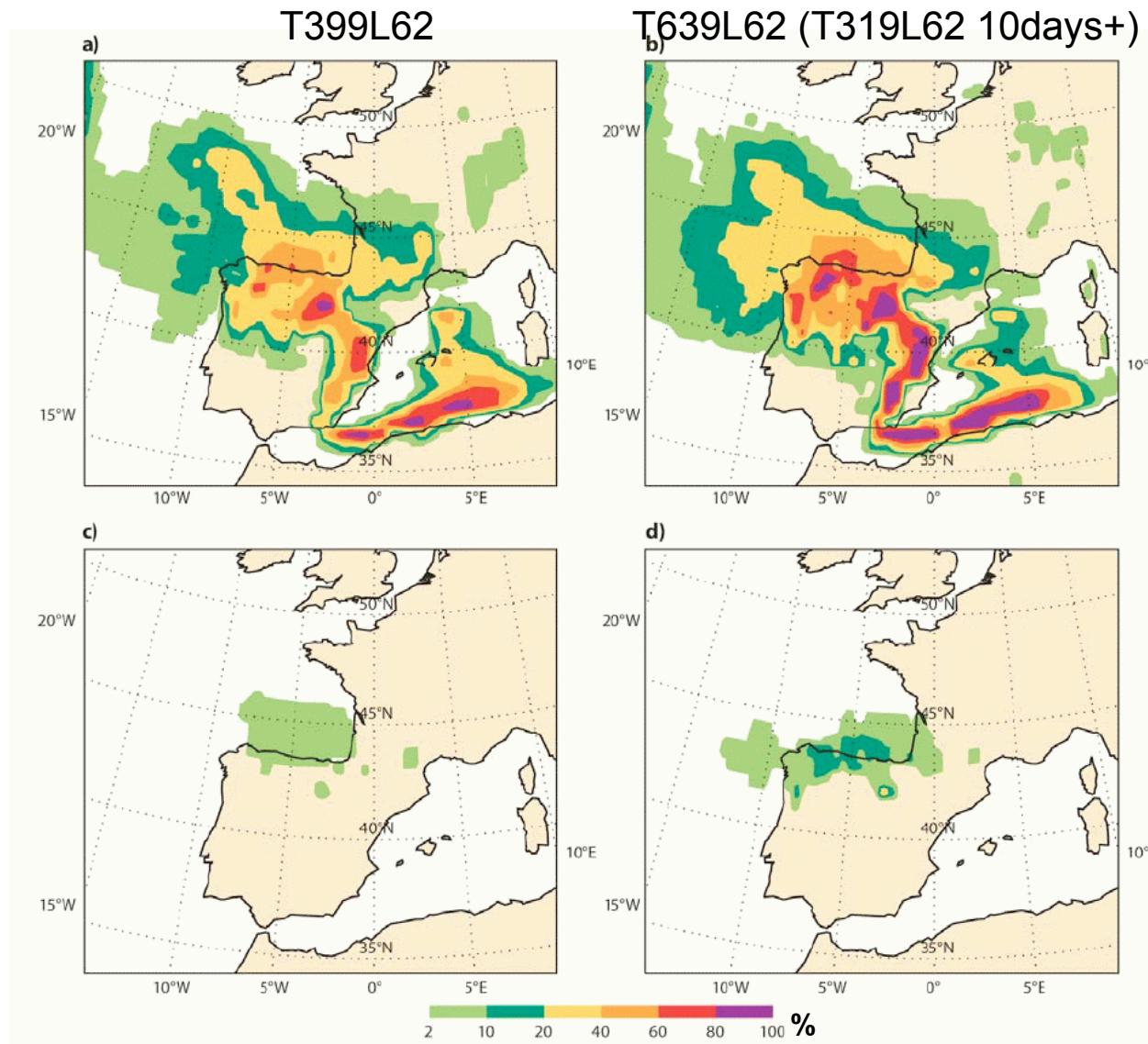
Improved Huber norm QC also beneficial



Hurricane Bill,
20 Aug. 2009
Observed MSL
pressure~944 hPa



Impact of resolution upgrade

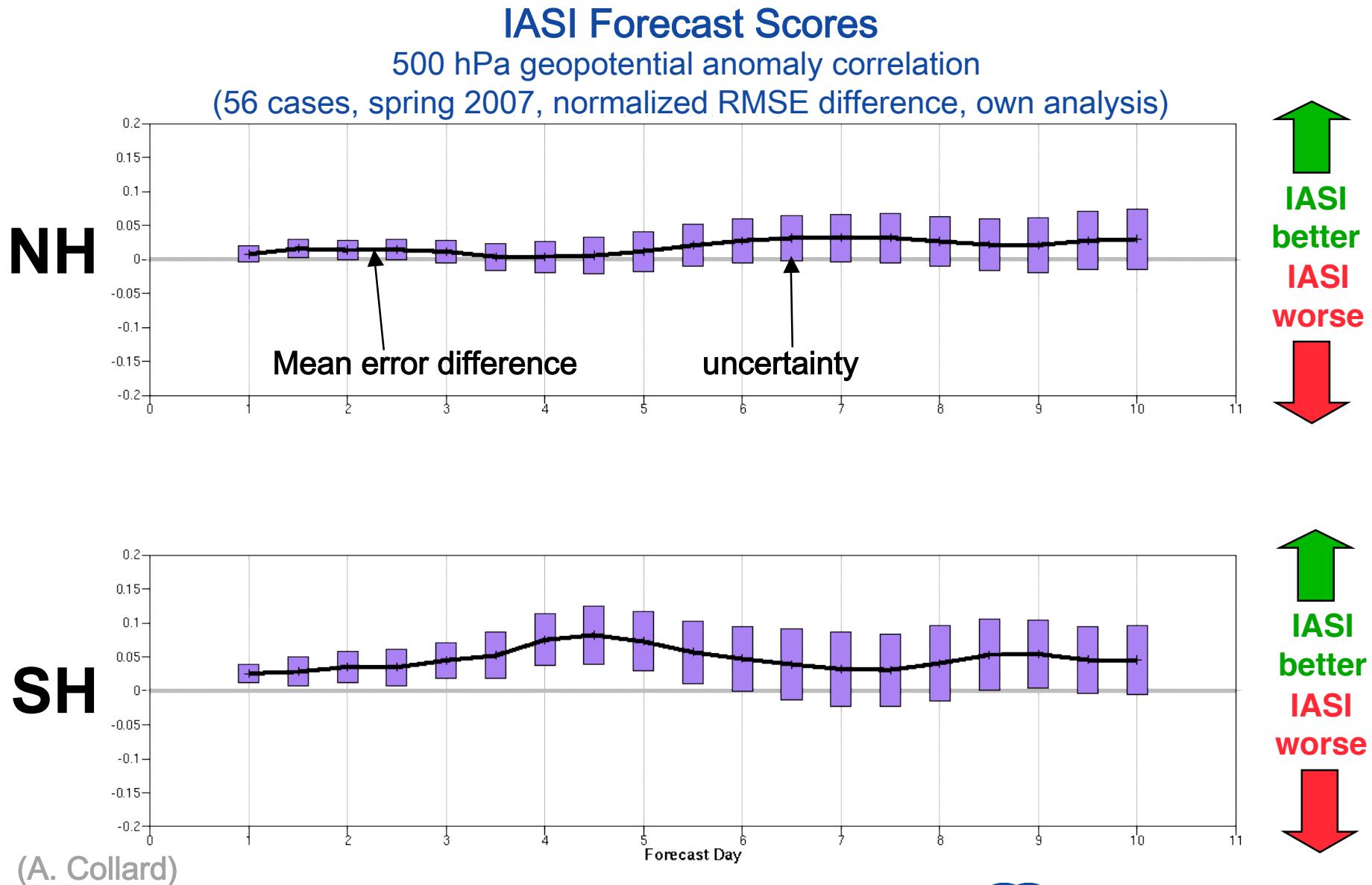


10 meter wind gust
occurrence probability:

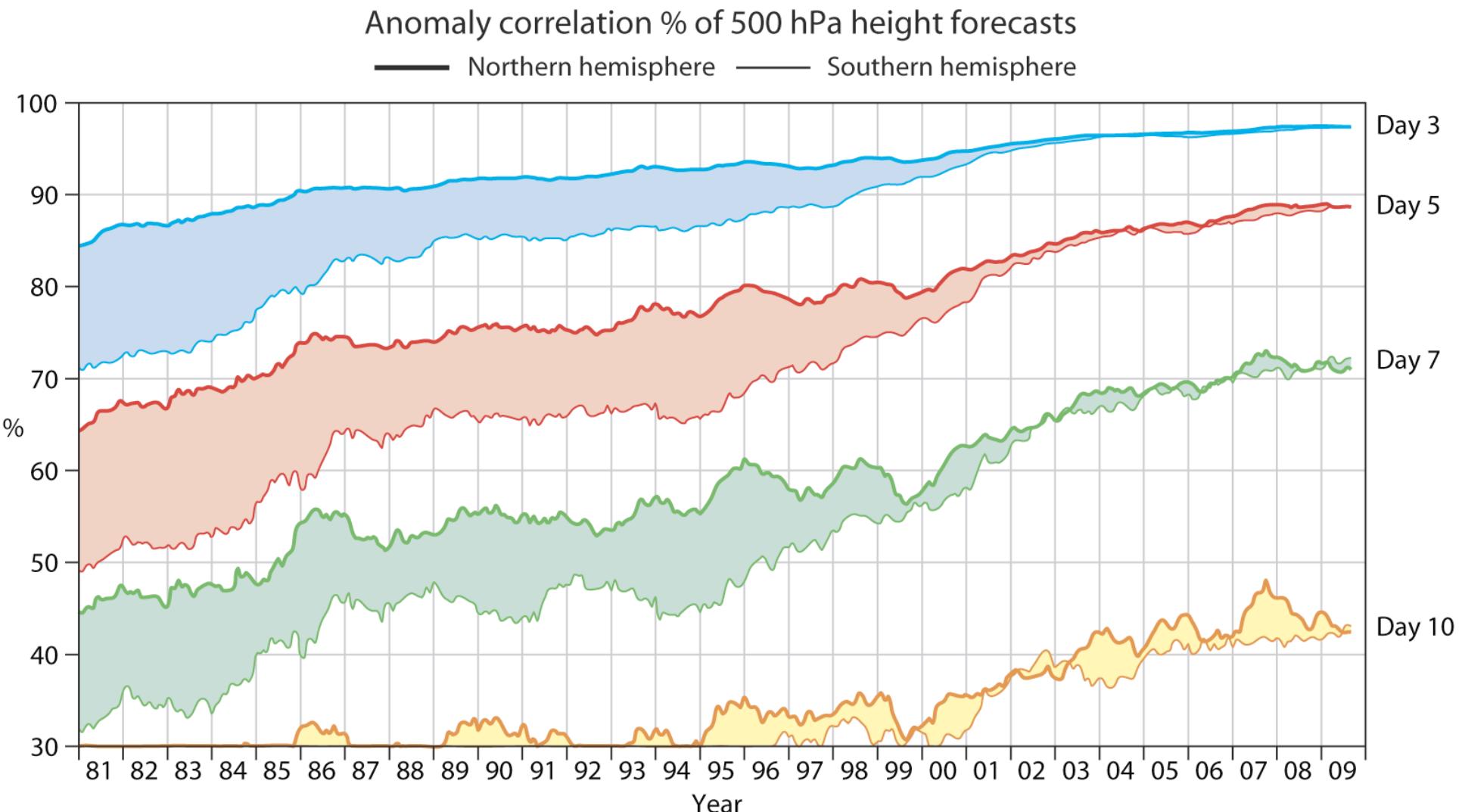
> 24 m/s

> 35 m/s

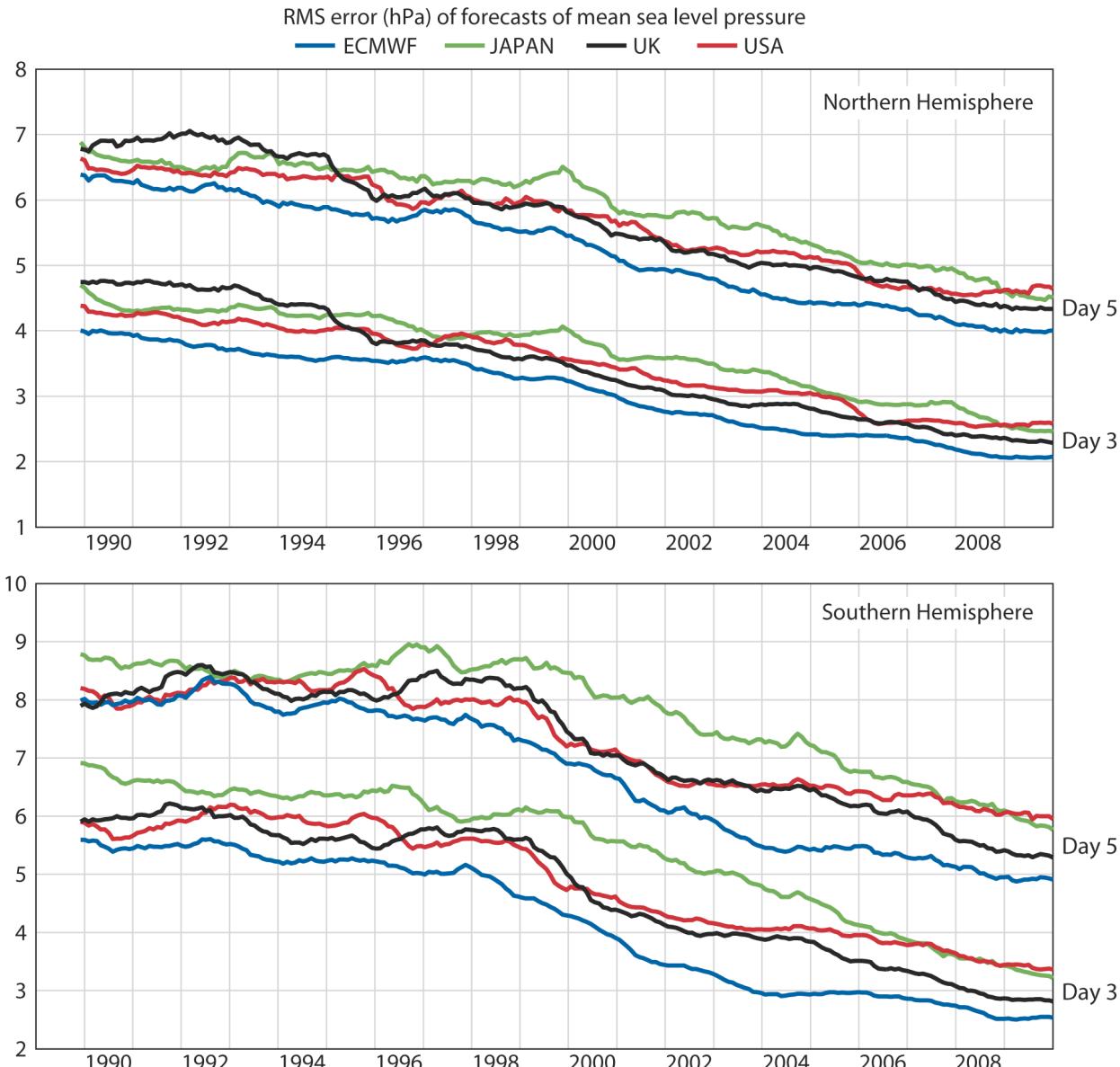
IASI NWP impact prior to implementation (12/06/07)



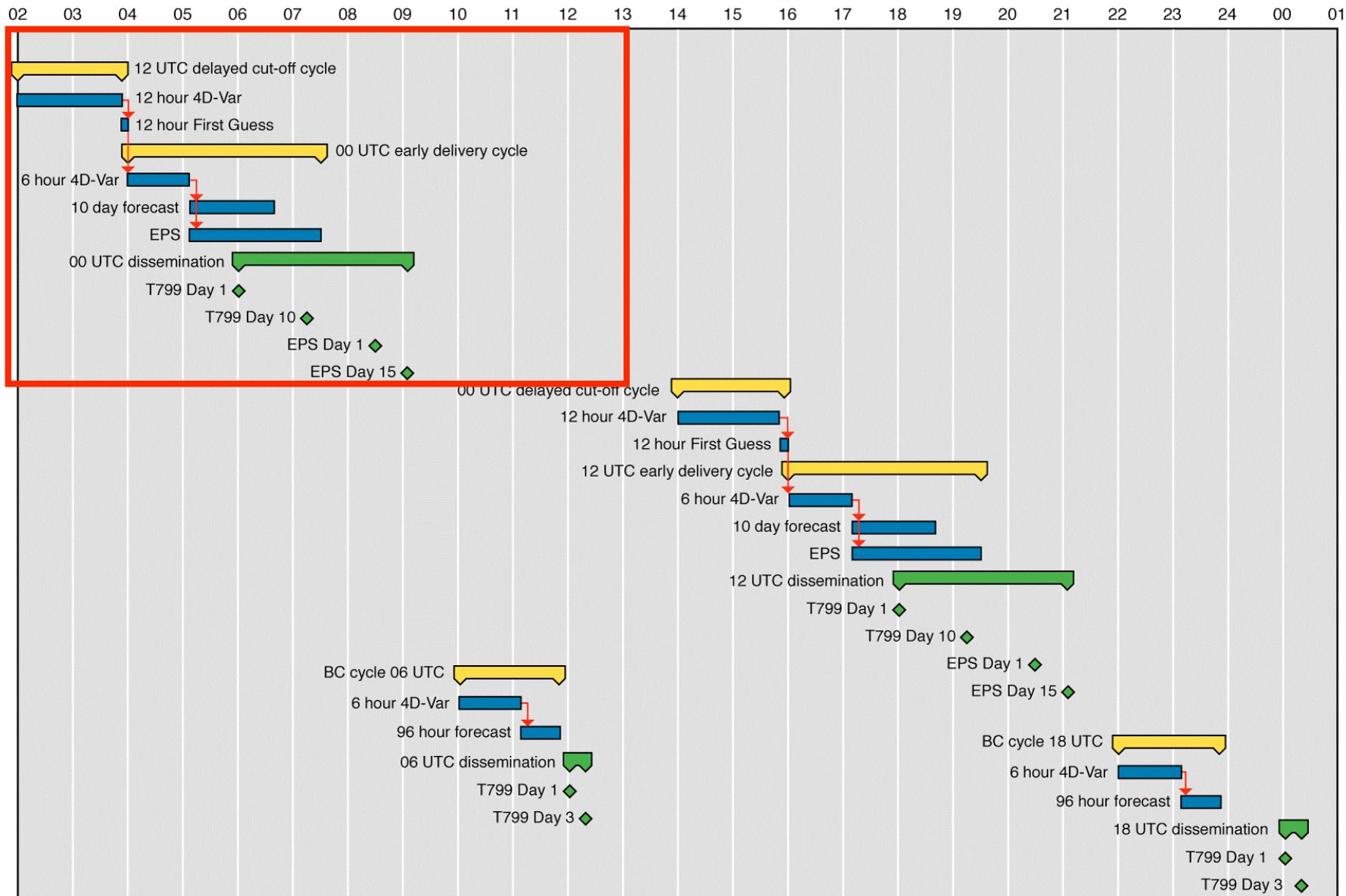
ECMWF model forecast performance



ECMWF model forecast performance



ECMWF model suites

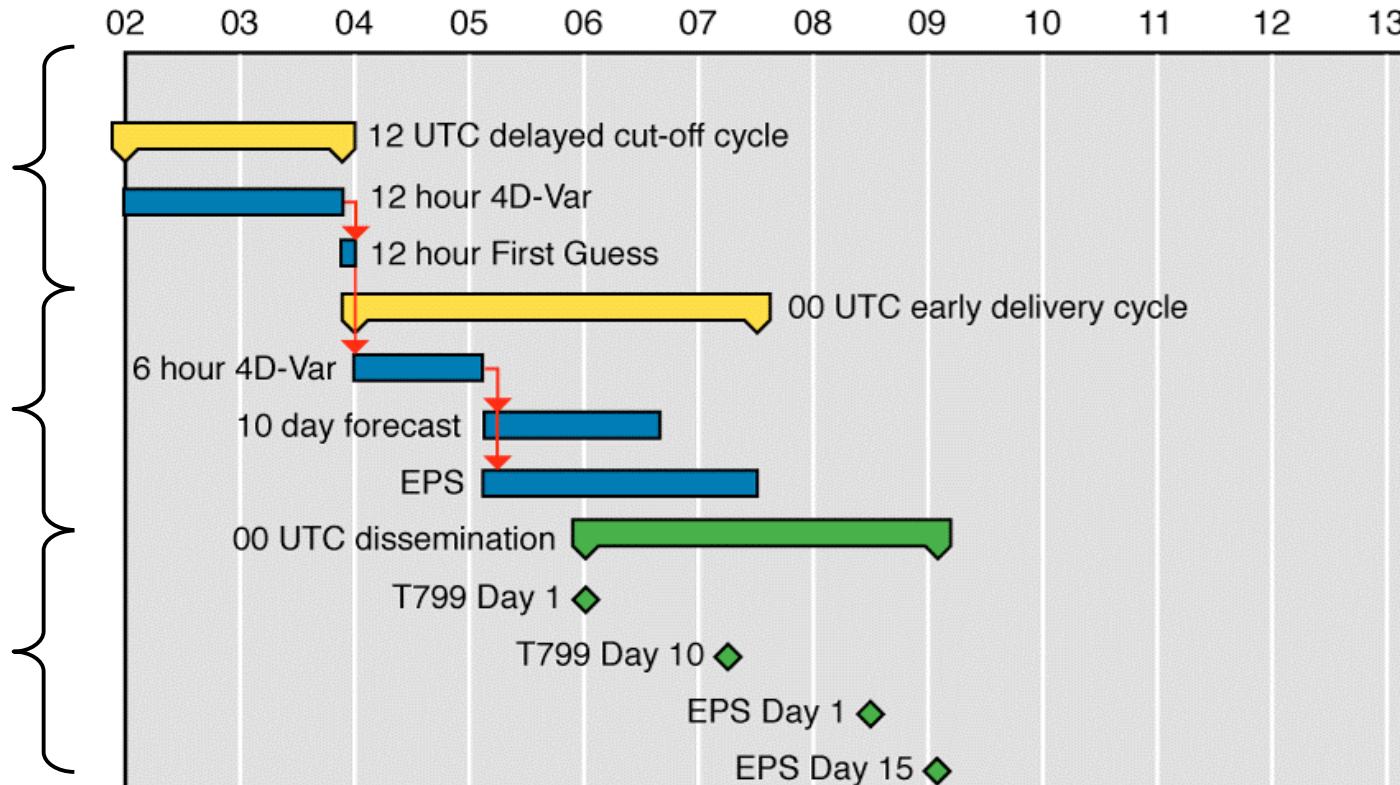


ECMWF model suites

Delayed cut-off suite provides short-range forecast for ...

Early delivery suite that initializes ...

Medium-range forecast



Data extraction start times for each suite:

Analysis	Observation window	Observation file	Extraction start
00 DA	21-03	21-03	04:00
00 DCDA	21-09	21-03 03-09	13:45 14:00
12 DA	09-15	09-15	16:00
12 DCDA	09-21	09-15 15-21	01:45 02:00
06 SCDA	03-09	03-09	10:00
18 SCDA	15-21	15-21	22:00

Data sources: Conventional

SYNOP/SHIP/METAR:

- Meteorological/aeronautical land surface weather stations (2m-temperature, dew-point temperature, 10m-wind)
- Ships
 - **temperature, dew-point temperature, wind (land: 2m, ships: 25m)**

BUOYS:

- Moored buoys (TAO, PIRATA)
- Drifters
 - **temperature, pressure, wind**

TEMP/TEMPSHIP/DROPSONDES:

- Radiosondes
- ASAPs (commercial ships replacing stationary weather ships)
- Dropsondes released from aircrafts (NOAA, Met Office, tropical cyclones, experimental field campaigns, e.g., FASTEX, NORPEX)
 - **temperature, humidity, pressure, wind profiles**

PROFILERS:

- UHF/VHF Doppler radars (Europe, US, Japan)
 - **wind profiles**

Aircraft:

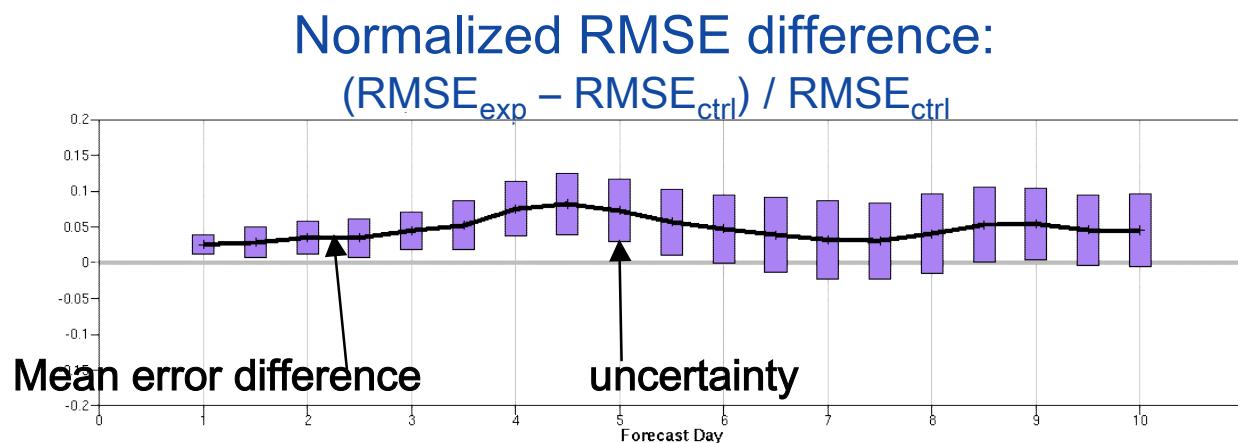
- AIREPS (manual reports from pilots)
- AMDARs, ACARS, etc. (automated readings)
 - **temperature, pressure, wind profiles**

Experiment verification

Forecasts:

- verification against experiment's own analyses,
- verification against operational analyses,
- verification against observations,
incl. information on statistical significance.

→ Accuracy (anomaly correlation, root-mean-square error) of selected meteorological parameter (T , q , z , R) forecasts at significant model heights (1000, 750, 500, 200 hPa): Better observing system should improve analysis and medium-range forecast, i.e. be closer to means of verification.

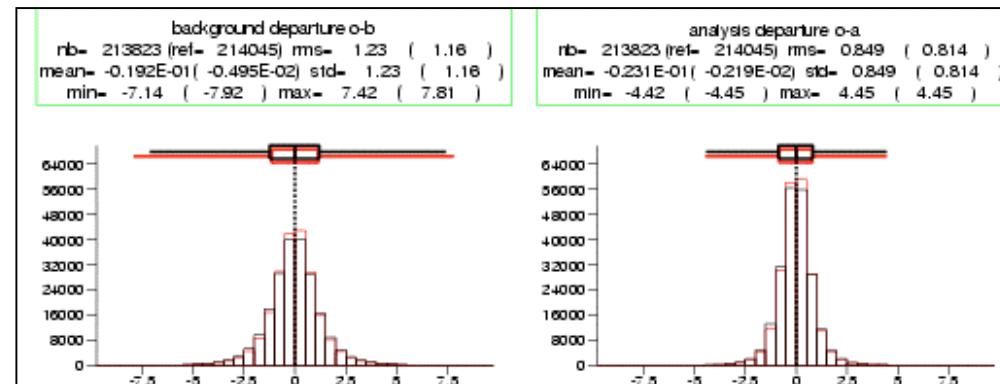


Experiment verification

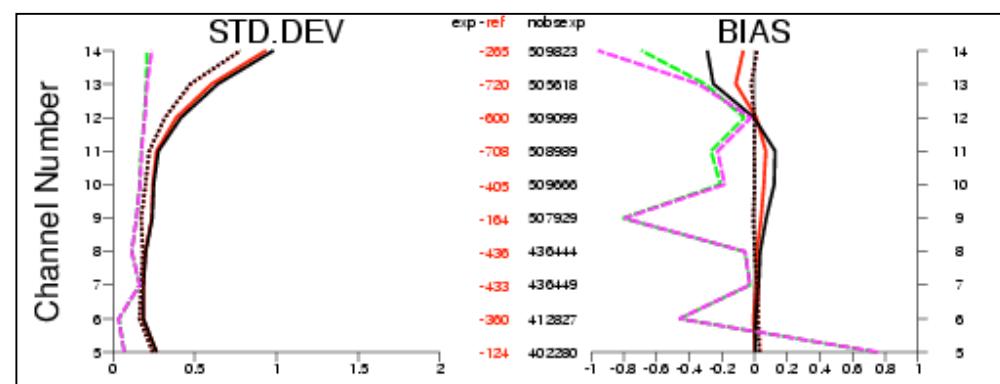
Analyses:

→ Fit (bias and standard deviation) of observations (in-situ and remotely sensed) to model first guess and analysis: Better observing system should improve analysis and short-range forecast, i.e. draw closer to entire observed data set.

Single-level observation



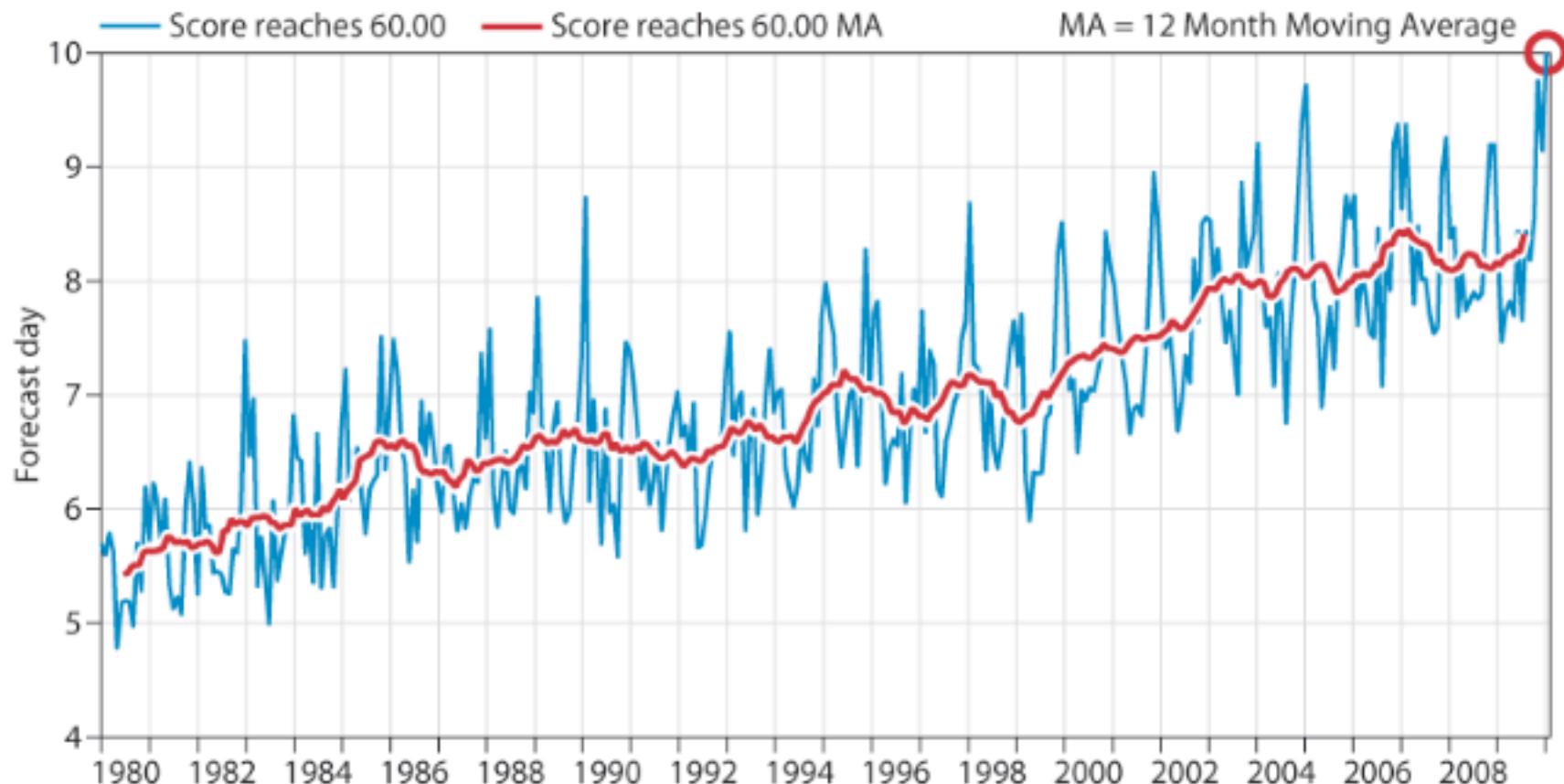
Multiple level/channel observation



ECMWF model forecast performance - NH

ECMWF forecast verification 12 UTC 500 hPa geopotential

Anomaly correlation forecast N. Hemisphere; latitude 20.0 to 90.0, longitude -180.0 to 180.0



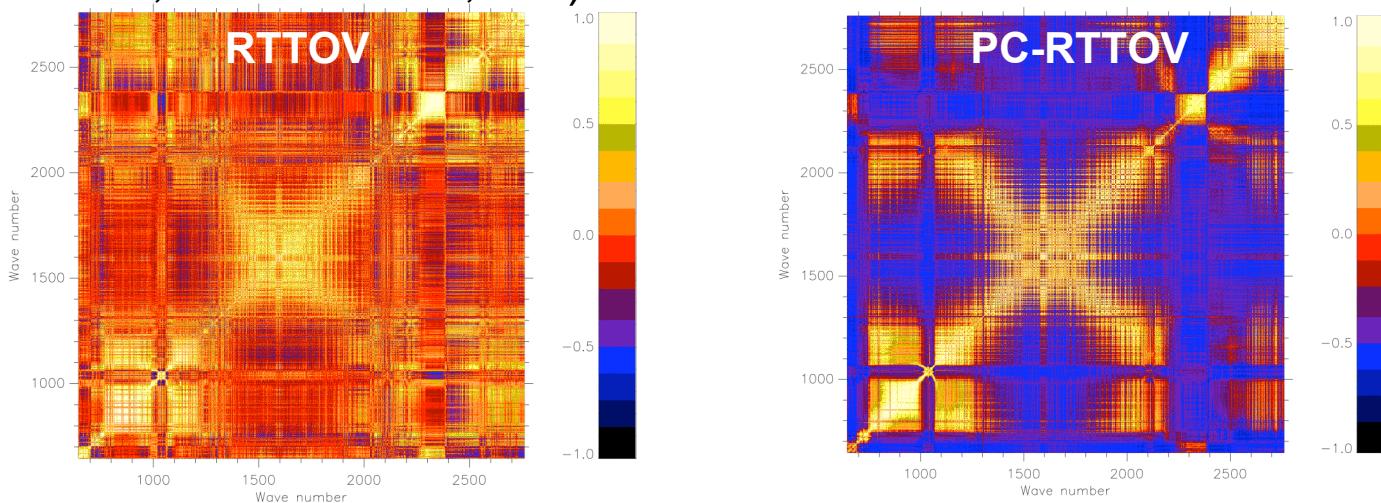
Principal component radiative transfer

Objective: Fast radiative transfer calculations *and* exploitation of the full information content contained in the IASI spectrum

Method:

- Development of PC calculation inside RTTOV fast model with minimal code structure modification (including tangent-linear and adjoint model)
- Test accuracy with respect to line-by-line and conventional RTTOV radiance calculations (also against radiance observations)
- Plans:
 - Apply PC-RTTOV to IASI shortwave band (denoising)
 - Further extend to full spectrum (potential issues with: Jacobians, cloud detection, land surfaces, etc.)

Simulated
error
correlation
spectrum:

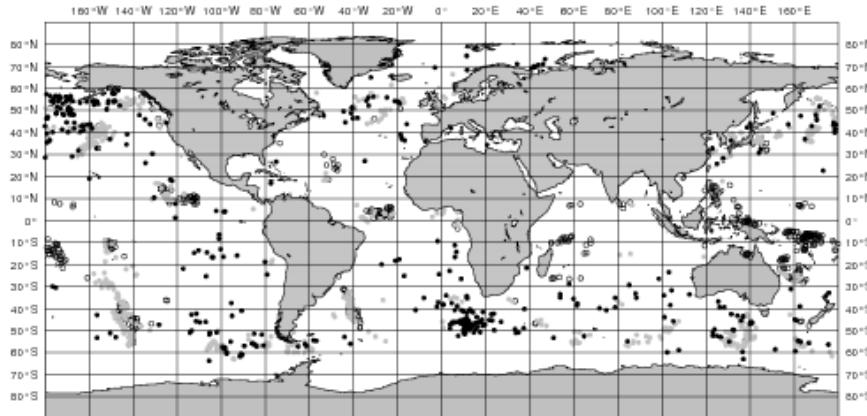


(M. Matricardi)

Assimilation of cloud-affected channels

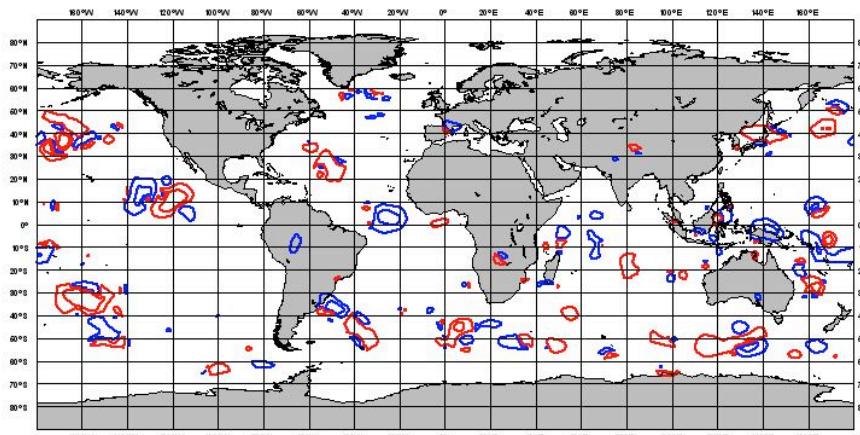
First cycle overcast HIRS, AIRS, IASI

- 800-600 hPa, ● 600-300 hPa, ○ 300-100 hPa

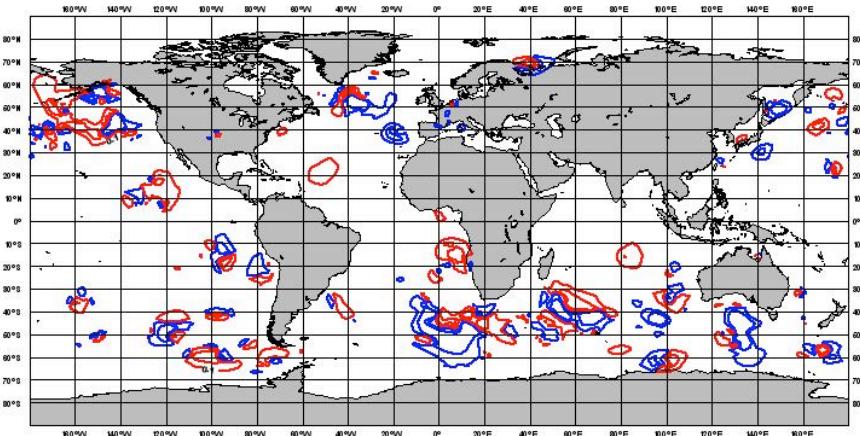


positive
negative
0.2 K intervals

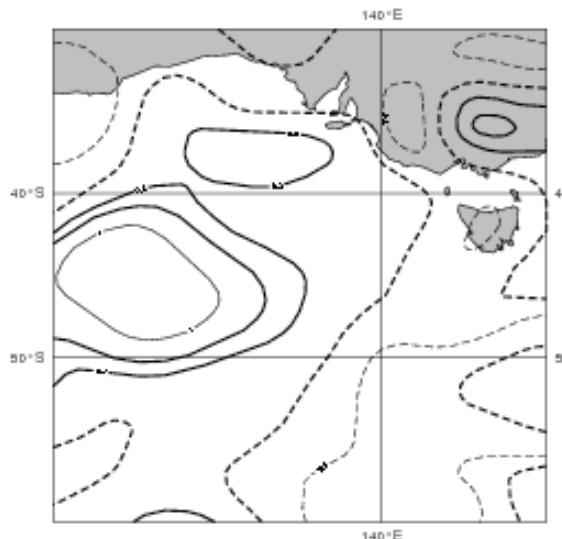
First cycle temperature increment
difference EXP-CTRL
250 hPa



700 hPa

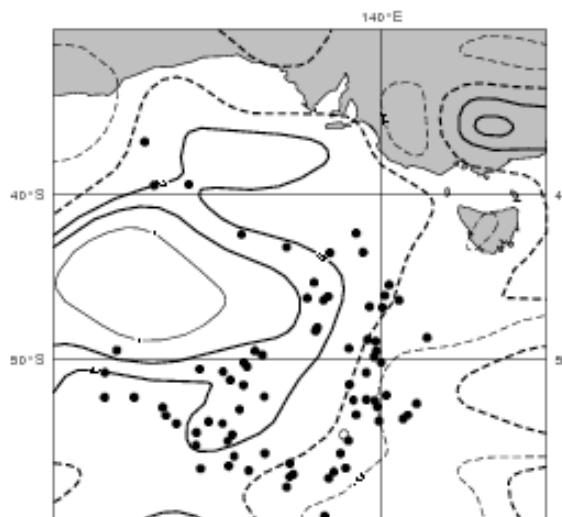


Assimilation of cloud-affected channels

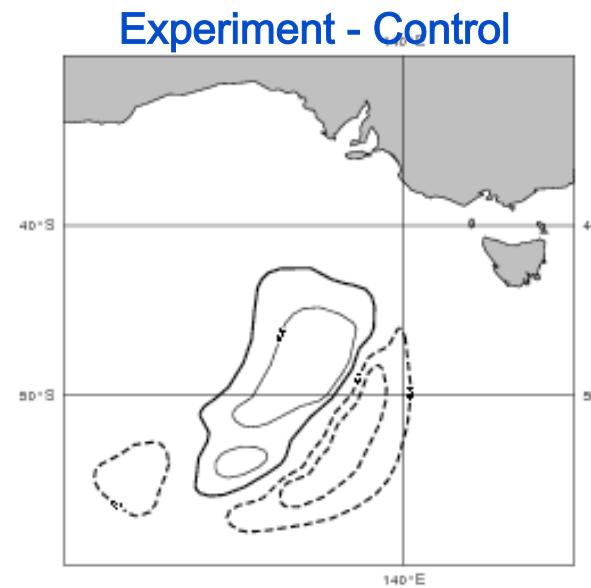


First cycle temperature increment 250 hPa
(0.2, 0.5, 1 K intervals)

Experiment



Control
(dots are overcast data)



Supporting States and Co-operation

Belgium
Denmark
Germany
Spain
France
Greece

Ireland
Italy
Luxembourg
The Netherlands
Norway
Austria

Portugal
Switzerland
Finland
Sweden
Turkey
United Kingdom

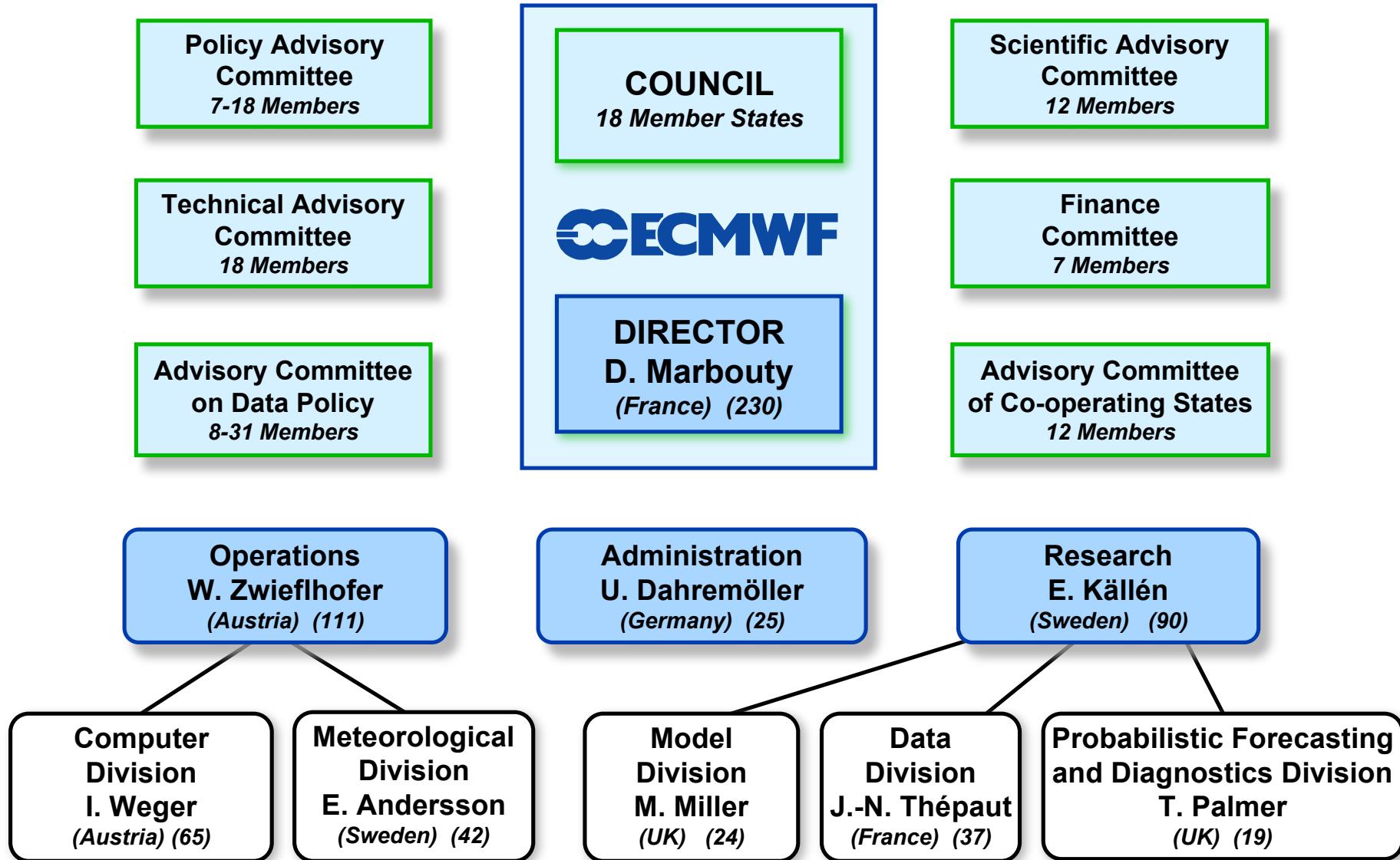
Co-operation agreements or working arrangements with:

Czech Republic
Croatia
Estonia
Hungary
Iceland
Latvia
Lithuania

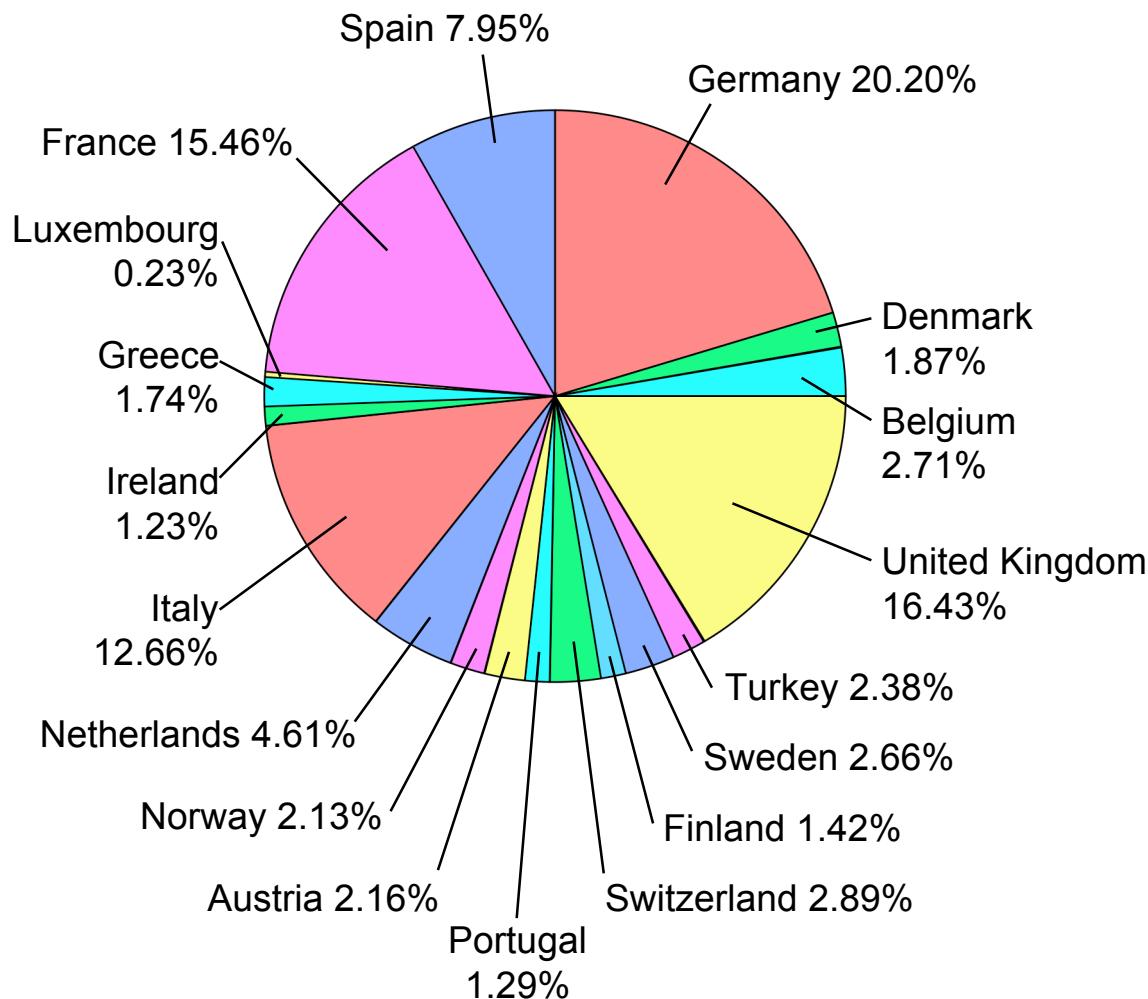
Montenegro
Morocco
Romania
Serbia
Slovakia
Slovenia

ACMAD
ESA
EUMETSAT
WMO
JRC
CTBTO
CLRTAP

Organisation of ECMWF



ECMWF Budget 2009



GNI Scale 2009–2011

Main Revenue 2009	
Member States' contributions	£35,593,300
Co-operating States' contributions	£847,400
Other Revenue	£1,169,500
Total	£37,610,200

Main Expenditure 2009	
Staff	£14,450,100
Leaving Allowances & Pensions	£2,965,200
Computer Expenditure	£15,690,600
Buildings	£3,634,300
Supplies	£870,000
Total	£37,610,200

ECMWF model forecast performance - Europe

